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THE DEVELOPMENT OF NEW DREDGING PROCEDURES.(U)

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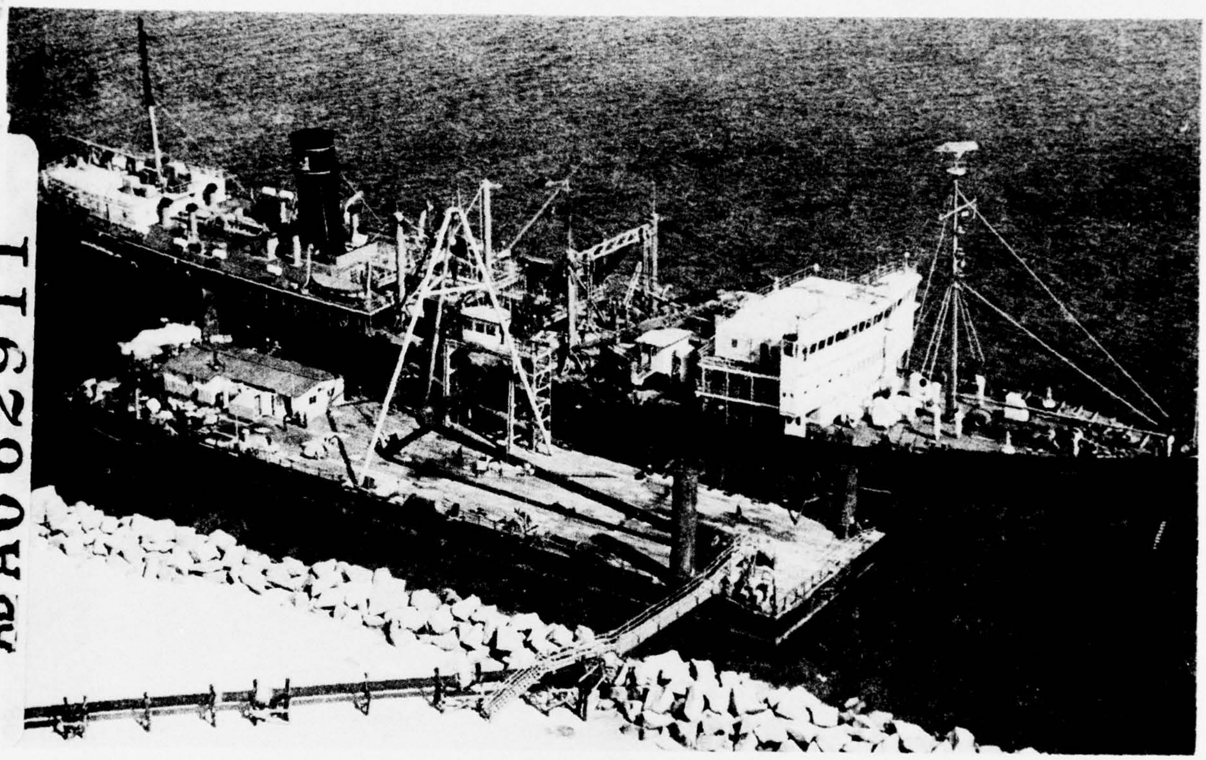
The Development of New Dredging Procedures



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This report describes and evaluates three field tests conducted to determine the feasibility of using seagoing hopper dredges to obtain materials from the offshore zone for delivery to eroded beaches. The tests were conducted at Sea Girt, New Jersey; Jacksonville, Florida and Virginia Beach, Virginia. The tests focused on the capabilities of the dredging equipment, including the systems of equipment used to deliver dredged material to beach areas, and on the operation practices employed in dredging and delivery. As a result of the tests and their evaluation the author concludes that advances in the

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CONT capabilities of dredging equipment are conducive to increased use of seagoing hopper dredges for excavation of material from the offshore zone and delivery to beach areas. The report includes recommendations for further testing of alternative systems for delivery of dredged material to eroded beaches, including components such as mooring buoys, flexible connectors and discharge pipelines. The report also identifies the need for a national study of the availability of materials in the offshore zone for use in beach nourishment.

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ABSTRACT

THE DEVELOPMENT OF NEW DREDGING PROCEDURES

PURPOSE

The primary purpose of the paper is to make a contribution to the advancement of marine technology in the field of dredging by describing the conditions that have led to the development of new equipment and operational procedures.

A secondary purpose is to make the public more aware of the social and economic importance of dredging activities. Virtually all of the major ports in the world require dredging to provide access for ships engaged in domestic and international maritime commerce. In spite of the importance of dredging to our national economy, few people are aware of the basic fundamentals involved in this industry.

METHODOLOGY

The descriptive study approach was utilized. This method was selected because the study includes a summary of the facts and circumstances associated with three test operations involving the use of a seagoing, self-propelled, hydraulic, hopper dredge.

Each test was conducted to determine the operational, environmental and economic feasibility of excavating material from deposits located in open water areas, transportation of the material to a mooring

arrangement and the discharge of the material to nourish eroded beaches.

The information derived from the tests at Sea Girt, New Jersey; Jacksonville, Florida; and Virginia Beach, Virginia, is presented and evaluated.

HYPOTHESES

It was hypothesized that the design features recently installed on seagoing, self-propelled, hydraulic, hopper dredges have resulted in a type of equipment that can successfully, and within a reasonable cost range, provide materials from the offshore zone that are suitable for general construction and beach nourishment purposes; or dispose of polluted materials in diked containment areas.

It was also hypothesized that the equipment and operational procedures used in the three test operations will be suitable for an extended period--twenty to thirty years or more.

DELIMITATIONS

The various types of dredges and marine excavation procedures are described. However, the study is directed toward a comprehensive analysis of the feasibility of using seagoing hopper dredges to obtain materials from the offshore zone and the delivery of the materials to eroded beaches.

The test operations described do not include

the excavation of compact or rock materials that require the use of explosives.

Environmental factors and legislation, which have contributed to the need for new dredging equipment and procedures are discussed in general terms and only as they related to the three test operations discussed in the study.

CONCLUSIONS

1. A shortage of sand and gravel exists in the United States. The major factors relating to the shortage are as follows:

The materials located in many estuaries and onshore areas have been depleted.

Legislation, based on environmental considerations, preclude the use of available materials in some locations.

The population growth and the concentration of the population in the coastal zone have resulted in increased requirements.

The rising standard of living, with the associated need for new facilities, has resulted in increased requirements.

The development of the coastal areas has resulted in the erosion of the shoreline in many areas; with the associated need for nourishment of the beaches.

The increasing number of offshore facilities such as nuclear power plants, petroleum off-loading and drilling facilities and off-shore ports has led to increased requirements.

The increasing trend toward the creation of marshlands and upland habitat has led to increased requirements for sand and gravel.

2. Large quantities of material suitable for general construction and beach nourishment purposes exist in the offshore zone.

The Inner Continental Shelf Sediment and Structure Survey, formerly called the Sand Inventory Program, initiated in 1964 by the Coastal Engineering Research Center of the Corps of Engineers, has identified vast quantities of materials that are suitable for general construction and beach nourishment use.

As indicated in the review of the literature, the engineering community is in general agreement that vast quantities of suitable materials exist in the offshore zone and that the materials are widely distributed and near many of the areas where serious shortages exist.

3. Significant improvements in the design and capabilities of marine equipment, including dredges, have occurred during the past twenty years.

The review of the literature indicates that design improvements in the capabilities of dredges, particularly hopper dredges, have made it operationally, environmentally and economically feasible to excavate material from the offshore zone and deliver the material to eroded beaches.

The hopper dredging process reduces the degree of pollution in the excavation of materials from waterways due to the introduction of dilution water.

A seagoing, self-propelled, hydraulic, hopper dredge is best suited to withstand the adverse wind and wave conditions that occur in the offshore zone.

4. The erosion of the shoreline is a large-scale and serious national problem.

About 20,500 miles of the total shoreline length of 84,300 miles are undergoing a significant rate of erosion.

About 2,700 miles of the total shoreline length are undergoing a critical rate of erosion.

5. An evaluation of the information developed during the three test operations described in the study indicates the following:

The seagoing, self-propelled, hydraulic, hopper dredge GOETHALS proved to be entirely suitable to excavate material from the offshore zone and deliver the material to eroded beaches.

6. The most effective mooring arrangement consisted of a self-elevating DeLong Pier Barge coupled to a floating mooring barge equipped to handle the discharge pipeline connections.

7. Booster pump units will be required within 8,000' intervals of the discharge pipeline length.

8. The success of the three test operations described in the study will lead to a significant increase in the use of hopper dredges to excavate material from the offshore zone and delivery of the material to eroded beaches.

RECOMMENDATIONS

Recommendations for actions that should be taken in the near future are as follows:

1. A test operation to excavate material from the offshore zone and delivery of the material to an eroded beach should be conducted. The test should include the use of a self elevating DeLong Pier Barge equipped to handle the discharge pipeline connections. The test should include the

use of at least one booster pump station and a hopper dredge equipped with sliding trunnion-dragarms to minimize the fendering arrangement between the dredge and the barge.

2. The Corps of Engineers should procure rubber-pneumatic fenders of the Yokohama type and two booster pump units for use during future test operations.

Recommendations for further study are as follows:

1. An evaluation should be made of the feasibility of utilizing a flexible and buoyant type of rubber pipeline to provide a connection between the mooring barge and the submerged pipeline.

2. A study should be made of the feasibility of designing components for the installation of trestle sections for the surface mounting of the discharge pipeline between the mooring barge and the shoreline.

3. A study should be made of the feasibility of utilizing a large buoy of the single point mooring type to serve as the mooring facility for unloading hopper dredges in the offshore zone.

4. A study should be made of the offshore deposits that are suitable and within a reasonable distance of eroded beaches.

5. The results developed from future test operations should be consolidated with the results of the three tests discussed in this study and a mathematical model developed for predicting cycle times and production rates for future operations.

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PREFACE

This paper is dedicated to the advancement of marine technology in general and to dredging activities in particular.

It is difficult to determine why the people engaged in marine construction chose to enter this field because it frequently involves demanding and sometimes dangerous work. Yet, it is essential in many areas to provide access between the land and the sea. Perhaps the romance and fascination associated with the sea, as indicated in the poem, "Sea Fever," by John Masefield, is the underlying cause:

> I must go down to the seas again, to the lonely sea and the sky,
> And all I ask is a tall ship and a star to steer her by;
> And the wheel's kick and the wind's song and the white sails shaking,
> And a grey mist on the sea's face, and a grey dawn breaking.
>
> I must go down to the seas again, for the call of the running tide,
> Is a wild call and a clear call that may not be denied;
> And all I ask is a windy day with the white clouds flying,
> And the flung spray and the blown spume, and the sea gulls crying.
>
> I must go down to the seas again, to the vagrant gypsy life,
> To the gull's way and the whale's way, where the wind's like a whetted knife;
> And all I ask is a merry yarn from a laughing fellow-rover,
> And quiet sleep and a sweet dream when the long trick's over.

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Chapter 1

INTRODUCTION

From the beginning of civilization and the evolution of established communities, there has been a need to transport people, as well as materials, supplies, and other commodities by water. This need resulted in the requirement that the natural depths of many estuaries and waterways be increased to provide access channels, ports and harbors for vessels.[1] The procedures utilized in the excavation of underwater materials to improve navigation and waterway conditions have become known as dredging. Virtually all the major ports in the world require dredging on an annual or frequent cycle to provide access for ships engaged in domestic and international maritime commerce. For example, the natural controlling depth at the entrance to New York Harbor is only twenty-three feet and the minimum depth required to sustain present day commerce in this harbor today is forty-five feet.[2] The Port of Hamburg, Germany, is another example of the extent of dredging required to support waterborne commerce. By 1850, it was necessary to initiate dredging on a seventy-eight mile reach of the Elbe River to provide a depth of twelve feet at low tide so that ships could gain access to the Port of

Hamburg. Further, dredging was required as the size of ships increased, with twenty-three feet available in 1900, thirty-three feet in the 1920's, thirty-nine feet in the 1950's and forty-four feet in the 1970's. The Port of Hamburg officials have forecasted a need to further deepen the channel to forty-nine feet in the immediate future and are considering a long-term plan to provide a channel with a depth of sixty-five feet. The examples cited are typical of the need for dredging at most ports.[3] Thus, dredging is essential to the movement of large ships and to the economic well being of this country and to the world.

In spite of the importance of dredging, few people are even aware of the basic fundamentals involved in this industry. Obviously, the dredging industry needs to make the public more aware of its social and economic importance. This paper is intended to be a step in that direction.

BACKGROUND

Definitions of Dredging

The definition of dredging varies widely depending upon the reference source. The 1966 edition of Webster's Third New International Dictionary of the English Language (Unabridged) includes a variety of definitions as follows:

> Scooping or digging objects or earth from the bed of a body of water; use of an oblong iron frame with a bag net attached, or a similar apparatus for gathering fish, shell fish or natural history specimens; scooping or removing earth as in excavating or deepening stream

> or harbor channels, building levees, or digging ditches by a series of buckets on an endless chain; a pump or suction tube, or a single bucket or grab at the end of an arm; to catch, gather or pull out with a dredge - often used with "up" (silt and old refuse were dredged up from the river bottom); to bring to light or gather by deep searching (facts dredged from the records); to make a search of or dig deeply with or as if with a dredge (the harbor still is being dredged for boats sunk); to deepen with a dredging machine; excavate with a dredge (dredged a cutoff three blocks long); to use as a dredge; to search with or as if with a dredge (dredging for oysters); to sprinkle with a powdered substance; to coat food for sprinkling, as if with flour or sugar; to dust (hot ware) with dry enamel powder in dry process enameling; and the mining of metal-bearing sands from the bottom of a body of water.[4]

The definition by Dr. John B. Herbich in the 1975 edition of Coastal & Deep Ocean Dredging is very brief, "Dredging is a process of excavating and removing unwanted materials from the bottom of harbors and waterways."[5] In this instance it is clear that Dr. Herbich has referred to dredging only as it relates to the maintenance and improvement of waterways for navigation and possibly to the benefits of flood control.

The definition by Dr. J. G. Th. Linssen in the Proceedings of the First International Symposium on Dredging Technology, 1976, University of Kent, Canterbury, England, is brief also, "The term dredging refers to those methods of displacing soil which are characterized by excavation in the wet and disposal in-stream or onto the shore."[6] While this definition is more general, it is also limited to operations in waterways.

The 1948 edition of The Engineer School Manual, The Engineer Center, Fort Belvoir, Virginia, is slanted toward navigation and construction, "Dredging is the removal of material from underwater. This may be done for recovery of the material as in mining, for the production of concrete aggregate, or to open a channel as in canal or waterway construction."[7]

During the past fifteen to twenty years new dredging techniques have been developed and are in widespread usage. These new applications, such as dredging as a means of improving water quality through the placement of excavated materials in diked containment areas and the use of dredged materials for the nourishment of eroded beaches are new techniques that should be described in future editions of dictionaries, technical papers and books written on dredging operations.

Dredging, as discussed in this paper, is accomplished with self-propelled hydraulic hopper dredges for the purpose of maintaining or improving navigable depths of waterway projects and for the nourishment of eroded beaches. The procedures and equipment described do not relate to the excavation of compact or rock materials that require the use of explosives or to dredging techniques that have been developed for the purpose of removing polluted sediments from waterways. The equipment and procedures described

in the paper were developed by the Civil Works Directorate of the U. S. Army, Corps of Engineers in an attempt to meet new and challenging workload requirements in the nourishment or restoration of beaches. Due to his position in the Corps organization, and an interest in new developments, the writer was a major contributor to the planning, design, and implementation of new equipment and procedures.

History of Dredging

With the development of ancient civilizations, dredging began along the Nile, Euphrates, Tigris and Indus Rivers many thousands of years ago. It is estimated that canal dredging occurred in Sumeria and Egypt about 4000 B.C. and in Babylon and between the Euprates and the Tigris Rivers in Mesopotamia about 600 B.C. Historical documents also indicate that the first canal between the Nile and the Red Sea, was started in Egypt by Nikau II about 600 B.C. and completed under Darius I about 500 B.C.[8] These early forms of dredging were carried out using primitive methods and equipment, such as slaves manually using spades and baskets. For example, the Roman Legions, slaves and prisoners of war were often employed in large scale excavation and acqueduct projects throughout the Roman Empire. Many of the Roman infantry necessarily carried the prosiac spade in addition to the military baton and sword.[9]

Agitation was another form of dredging used during the early days of recorded history. In its original form it was performed using tree trunks, weighted by stones, which were dragged behind boats on the Indus River to stir the mud and sand into suspension. After being placed in suspension, the materials were then carried by the river currents to deeper water areas, which eliminated or reduced the size of the shoal that was impeding or blocking navigation.[10] A later form of agitation dredging involved the use of a Kraggelaar, or water harrow. This type of equipment was used in Middleburg, Holland in 1435. It was a ship-like affair with a harrow or plow device attached beneath the stern of the vessel. Propelled by sails and by the tide on underwater plates, it plowed, loosened and placed the bottom materials into suspension while the tide was ebbing. As late as 1800, the water harrow was in widespread use in some parts of Holland.[11] As a matter of fact, an adaptation of the water harrow principle is still used today, primarily to remove isolated shoals after a channel has been dredged with other equipment. The current version of this method consists of an iron or steel beam suspended and pulled from a tugboat along the bottom of a waterway to agitate and transfer the materials through suspension in order to create a reasonably level bottom surface to meet channel prism dimensional requirements.[12]

The "Bag and Spoon," the "Mud Mill," the "Endless Bucket" and the "Grab" were dredging methods developed in Europe. All of these methods were widely utilized until about the middle of the eighteenth century.[13] These methods, utilizing mechanical principles, have relatively low production rates and are time consuming. Nevertheless, many large scale canal, irrigation and flood control projects were successfully completed by the use of these techniques. The latter two methods, the endless bucket and grab bucket types of dredges, are still in widespread use today and are very effective when the bottom materials are compact or dense. The exact origin of these methods is not clear, but there seems to be little doubt that most of them were conceived and refined in The Netherlands and to a lesser degree in Italy.[14] One need spend little time in The Netherlands to realize that the myriad of canals and dikes in this country required the extensive use of dredging equipment over a long period of time. For example, Cooper (1974) stated:

> Toward the end of the 16th century the astonished inhabitants of Amsterdam saw an ingenious contraption at work in their harbour. A number of men, industriously pedalling, kept turning two enormous wooden wheels that were mounted on a flat barge. Between these wheels an endless chain of transverse wooden boards was bringing dripping mud to the surface and tipping it through a chute into a mud barge. This was the primitive ancestor of the bucket dredges - the most characteristic tool of the dredging industry.[15]

The invention of the centrifugal pump by LeDemour in 1732, the invention of the double-acting steam engine incorporating a separate condenser to utilize waste heat by James Watt in 1765, and the application of the centrifugal pump as a dredging tool, which was presented by Bazin at the Paris exposition in 1867, were significant steps in the birth of modern dredges.[16] With the advent of these inventions it was possible to utilize mechanical energy rather than that provided by men or horses. This led to dramatic increases in production quantities. While many adaptations have been made to these inventions, their basic principles are still in use today. It appears that Bazin should be credited with the first hydraulic suction dredge, Lebby with the first hydraulic hopper dredge and Alexis von Schmidt with the initial usage of a pipeline for the transportation of dredged materials for extended distances.[17]

Dredging, which before World War II, generally followed trial-and-error procedures, started to become of age in the 1950's. Since then there has been a considerable improvement in dredging equipment and procedures. In recent years dredging is playing an increasing part in activities not related to navigational improvements.[18] Dredging is being used today in the preparation of plant and factory sites; in the construction of land for residential developments; in the laying of pipelines offshore for the petrochemical industry and for sanitation and cooling water

outfalls; in the construction of airports, roadways and causeways; in the construction of dikes, levees and breakwaters; and in the construction of offshore harbors and terminals.

The increase in the size of ships during the past twenty years or so, particularly the trend toward larger tankers, resulted in the need for deepening channels in ports and harbors in many countries and the construction of artificial islands to serve as offshore ports and unloading facilities.[19] The increase in the size of tankers on a deadweight tonnage (DWT) basis from 16,500 DWT in 1945 to 550,000 DWT in 1976 is shown in Figure 1. Examples of major port facilities which have evolved during this period include Rotterdam, The Netherlands; Gulf de Fos, Dunkerque and Le Havre, France; Botany Bay, Australia; Richards Bay, South Africa; and the ports of Hong Kong and Singapore. While a great many large port facilities have been completed during the past twenty years, it appears that this type of improvement will continue.

Since 1960, there have been a series of port construction and improvement projects underway in several Mid-East countries. For example, during 1977 three major ports were under construction in Saudi Arabia and during the same year there were two major port expansion projects underway. The construction of these and other large scale projects in the Mid-East has led to a new generation of

cutterhead dredges, dictated by the need to excavate the very dense and hard limestone that exists in that part of the world. In just a few years, horsepower requirements have doubled, multiple pumps and submerged pumps have become the pattern rather than the exception, machinery automation and horizontal positioning equipment usage are commonplace and the overall construction of dredges is much sturdier. All because of the developments in the Mid-East.

After many years of attempting to control the erosion of the shorelines with groins and jetties, many coastal engineers have concluded that the only practical way of achieving this objective is to nourish or restore the eroded shorelines with material obtained through dredging.[20] Under this method the dredged materials are utilized to create a gentle bottom slope in the coastal zone area which will dissipate the energy of the waves breaking along the shoreline and in turn, minimize the erosion of beaches. Due to environmental constraints it is necessary to obtain the majority of the materials required for beach-nourishment projects from the offshore zone today, rather than from estuaries and interior waterways. The location of the materials in the offshore zone and the magnitude of the beach erosion problem has also led to the need for developing new procedures and equipment. This modernization aspect of dredging is the theme of this paper.

Dredging Objectives

A summary of the varied objectives of dredging operations is as follows:

Navigation. To maintain, increase, extend or otherwise improve waterways, harbors and channels.

To create harbors, basins, canals, marinas and other types of waterways.

Flood Control. To improve or maintain river discharge or flow capabilities by deepening natural water depths or by watercourse realignment.

To construct control structures or protective structures such as dams, dikes, levees, groins, jetties and breakwaters.

Construction and Reclamation. To provide construction materials such as sand, gravel, shell and clay.

To provide landfills, including the construction of highways, dams, airports and causeways.

Mining. To recover minerals, gems, precious metals and fertilizers.

Beach Nourishment. To provide fill material for the protection and replenishment of beaches, including the construction of protective dunes.

General. To excavate underwater for structure foundations and for the emplacement of pipelines and cables.

To provide for drainage in swampy or lowland areas.

To remove pollutants and improve water quality.

Types of Dredges

There are three basic types of dredging equipment, viz.: mechanical, hydraulic and pneumatic. Each type has certain degrees of adaptability to the materials to be dredged, the dredging depth, the means of disposal, the access to the site and the environmental factors.[21]

Mechanical dredges rely upon the mechanical shearing action between the excavator edge and the material to be removed. The various types of dredges in this category include bucket dredges, grab dredges, dipper dredges and scraper dredges. They vary greatly in size and capacity. While they may have some self-carrying capacity on the mounting vessel, they are usually used in conjunction with separate disposal equipment such as self-propelled or towed barges and scows. Mechanical dredges are the most efficient types when compact or rock materials must be excavated and are the type most often used when blasting is required. A unit cost comparison should not be attempted between mechanical, hydraulic and pneumatic types of dredges since they are utilized for entirely different purposes. The cost per cubic yard of material excavated with mechanical dredges is usually much greater than the cost per cubic yard of material excavated with hydraulic dredges. This is usually due to the fact that the material removed by mechanical dredges is much more dense and difficult to excavate than

the softer materials normally excavated by hydraulic dredges. Even when soft materials are involved, the cost per cubic yard for mechanical dredges is greater than hydraulic dredges if large quantities of materials are to be excavated. Nagel (1974) indicated that tests have shown that in maintenance dredging the cost of working with bucket chain dredges is about three times as high as working with hopper suction dredges. In maintenance dredging the use of bucket chain dredges is therefore not economical, if the work can be done by hopper suction dredges. Nagel also indicated that the traffic of ships is considerably hindered by the use of cumbersome bucket chain dredges with their long moorings and that this is a major factor in harbor entrances, particularly on the heavily frequented Elbe River, which has an annual traffic of 100,000 ocean-going ships.[22]

Hydraulic dredges utilize the principle of the centrifugal pump, whereby a vacuum is created on the intake or suction side of the pump casing by the rotation of an impeller. Material dislodged from the bottom of the waterway is suspended in water in the form of a slurry and then forced through the pump and the discharge pipe to the disposal site. The excavated materials may be discharged into hoppers within the dredge, auxiliary hopper barges or scows, or through discharge lines to shore or water disposal sites. This category includes pipeline-

suction dredges, hopper-suction dredges and sidecasting or boom dredges.[23] Hydraulic dredges have a high production rate when the materials to be excavated are soft and contain a high ratio of water. They can be utilized in materials which are fairly dense but cannot compete with mechancial dredges when the materials to be excavated are very dense and compact. Hydraulic dredges require a greater capital investment than mechanical dredges and are therefore not competitive with mechanical dredges when the volume of material to be excavated is small.

Pneumatic dredges operate by means of compressed air, with the intake suction created by the pressure differential between that in the pump chambers and the ambient water head. This is a relatively recent development in the dredging field with limited present use. The widest usage of this type of equipment has been in Italy, Japan and the United States. The most efficient use of this type of equipment is in soft materials. Since there is no mechanical shearing action involved in the excavating process, the system minimizes agitation at the dredging site, which is a major advantage when the material to be dredged is polluted.[24] The cost per cubic yard of material excavated is quite high for this type of dredge for two reasons. First, they have been utilized largely for the removal of pollutants in the United States with the associated safeguards to protect the environment. Secondly,

the volume of material removed in each job completed to date has been very small. For the reasons cited above, it is not possible to make a valid comparison between the different types of dredges since they were designed to meet entirely different circumstances.

Environmental Considerations

Dredging and the related disposal of dredged materials inherently involves changes in the status quo at the dredging site, along the disposal route and at the disposal site. Hence, the environment is invariably affected to some degree. These changes may be beneficial or detrimental.

The primary beneficial effects include the larger and improved availability of facilities which contribute to the welfare of mankind, such as in the construction of new harbors, canals, dikes and land fills, and in the case of dredging for the maintenance of existing channels, ports, canals, rivers and lakes. These types of activities are required to support organized communities and provide benefits of a social and economic nature.

Maintenance dredging may have as a further goal the restoration of previous conditions to achieve an environmental equilibrium, either natural or artificial, when these conditions have been altered by natural events, as in the case of restoring the geometry of a river section

or a harbor bed or for the removal of pollutants from the bed of a waterway. Recently, the removal of polluted sediments for the sole purpose of pollution control or abatement has become more and more frequent.[25]

At any dredging site adverse effects may occur such as turbulence, turbidity--through the suspension of sediments, impairment of biological activities and discomforture to the nearby human population due to vibration, noise and vista impairment. On the other hand, the same activity that results in adverse effects may provide some beneficial effects; for example, the suspension of nutrients from the bottom sediments making them available to the aquatic biota, or the reoxygenation of the water column as a result of turbulence. However, there are some effects resulting from dredging that are totally detrimental such as the disposal of highly polluted materials into a pristime marsh area serving as a nursery for aquatic species. Harmful effects can also result from the use of inefficient equipment and methods, including the introduction of oil and fuel into the water, the emission of toxic exhaust gases and the spillage of polluted materials while in transit from the dredging area to the disposal site.[26]

The beneficial and detrimental effects of dredging should be viewed from the following aspects:

The spatial extent to which they are manifest, whether at the dredging site, nearby or at a remote distance; and

The temporal extent during which they are expressed, either immediately or in the short (25 year span), medium (25 to 50 Years) or long term (greater than 50 years).

STATEMENT OF THE PROBLEM

For many years the justifications for the construction and maintenance of Federal navigation and beach-nourishment projects were based on the cost of construction as compared to the monetary benefits which would be derived during the economic cycles of the projects. However, on January 1, 1970, the National Environmental Policy Act of 1969 was approved (P.L. 91-190) as a result of a growing awareness that pollution of the environment was becoming a major problem in the United States. The National Environmental Policy Act indicates that it is the policy of the Federal Government to use all practical means to create and maintain conditions under which man and nature can exist. The Act also refers to the objective of attaining the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.[27]

The major implementing provision of the National Environmental Policy Act indicates that all agencies of the Federal Government shall include in every recommendation

or proposal for major Federal actions significantly affecting the quality of the human environment, a detailed statement which has become known as an Environmental Impact Statement that delineates:

The environmental impact of the proposed action.

Any adverse environmental impacts which cannot be avoided if the proposal is implemented.

Alternatives to the proposed action.

The relationship between short-term uses of the environment and long-term productivity if the action is taken and;

Any irreversible commitment of resources involved in the proposed action.[28]

In most cases, the traditional methods of maintaining and improving depths in the major channels in the coastal regions do not provide for the beneficial use of the dredged materials. Disposal of these materials has been and continues to be mainly in deep water at sea, even in the case of sand, which in many instances could be used for the restoration or nourishment of eroded ocean beaches. This type of disposal has persisted even though there are a significant number of ocean beaches within reasonable distances of navigation-channel projects which must be dredged on an annual basis.[29]

For many years, the principal source of sand for beach nourishment purposes was from lagoonal and inland deposits. However, during the past fifteen years or so it has become increasingly difficult to obtain suitable sand from such sources in sufficient quantities and at economical costs due primarily to public and private developments in the estuarine areas and to restrictions related to the protection of the environment. Also, in many instances, bottom materials dredged from estuaries, lagoons and bays, because of their smaller grain size, are unsuitable for long term beach stabilization purposes. Even when suitable materials exist in such tideland areas, with the advent of environmental impact statements and assessments, its use is prohibited by legislation in most cases.

In recognition of environmental considerations and the related constraints that are applicable to the disposal of dredged materials, the U. S. Army, Corps of Engineers, has engaged in a broad effort to develop equipment and disposal procedures that will serve to enhance the beneficial aspects of dredging and minimize any detrimental effects of dredging.[30] The major part of this effort consists of a comprehensive research program planned for accomplishment during a five year period. This program,

known as the Dredged Material Research Program (DMRP), is scheduled for completion in 1978 and includes investigations that should lead to the development of more productive uses of dredged materials. The primary objective of the program is to provide definitive information on the environmental impact of dredging and to develop technically satisfactory, environmentally compatable, and economically feasible dredging and disposal alternatives. The program is being carried out by the Environmental Effects Laboratory of the Corps of Engineers located at the Waterways Experiment Station, Vicksburg, Mississippi. The program includes four phases:

Phase 1 -- Problem definition and assessment.

Phase 2 -- Development of the research program.

Phase 3 -- Research accomplishment.

Phase 4 -- Implementation of the test results.

During the course of this program, considerable attention has been given to the development of techniques to use sand dredged from navigation channels for beach-nourishment purposes and to locate suitable sources of sand for this purpose in the offshore zone. During the past thirteen years numerous sources of sand, involving large quantities at each site have been located in the offshore zone and in navigation channels by the Coastal Engineering Research Center of the U. S. Army, Corps of Engineers.[31] The availability of these materials and the

environmental constraints on the utilization of materials from estuaries for beach nourishment led to the problem of developing dredging equipment and procedures which could be utilized to excavate the materials, transport them to a site in the ocean or a bay near the shoreline and then pump the materials to nourish or restore eroded beaches. The factors that were involved in the development of a solution to this problem are discussed in this study.

PURPOSE AND SIGNIFICANCE

The purpose of this paper is to contribute to the advancement of marine technology in the field of dredging by describing the changing conditions that have led to the development of new equipment and procedures.

There are few harbors in the world of any magnitude that do not require dredging to provide flotation depths for the ships calling at the ports. In the early days of the development of the nation there were few restrictions on the methods of disposing of the materials excavated from the bottoms of estuaries and waterways.[32] This was due to the absence or limited amount of development along the shoreline.

As the nation has grown and the shorelines have been utilized for residential and industrial structures or for parks and pristine, wildlife-refuge areas it has become necessary to transport the dredged materials extensive

distances from the dredging sites. For example, instead of dumping the materials from a hopper dredge within one-half of a mile from the channel of Norfolk, Virginia, which was the procedure in the 1940's, it is now necessary to haul the material a one-way distance of five to ten miles and then pump the material into a diked containment area; or haul the material a one-way distance of about twenty-five miles and then dump the materials into deepwater areas of the Atlantic Ocean.[33]

In addition to the changes in dredging procedures brought about by the growth in the national population and the construction of factories, warehouses, piers, homes, marinas and recreational areas along the shorelines of the waterways, the concern for improving the environment has been another major factor in bringing about changes in the types of equipment and the procedures utilized in dredging operations. The National Environmental Policy Act of 1969 has produced the need for new types of equipment and procedures in many dredging operations.

Other laws have been passed relating to the environment. Under the provisions of Public Law 91-611,[34] any bottom materials which are removed from the Great Lakes and which are classified as polluted by the Environmental Protection Agency must be transported from the dredging sites and pumped into diked containment areas in order to protect and improve the water quality of the Great Lakes.

As a result of this legislation, the U. S. Army, Corps of Engineers, is in the process of constructing forty-six diked containment areas at a total cost of over 300 million dollars.[35] Ten of these containment areas have been completed, five are under construction and the remaining thirty-one containment areas will be constructed as quickly as sites can be located and the construction funds furnished by the Congress. The longest one-way haul distance to the new diked containment areas is thirty-three miles and the average one-way haul distance to those areas that will be completed in 1978 is 15.9 miles, as compared with the previous practice of dumping the excavated materials in open water within one or two miles of the dredging sites.

The Marine *Protection*, Research, and Sanctuaries Act of 1972, as amended by Public Law 94-326, is commonly referred to as the "Ocean Dumping Act."[36] This Act requires that a permit be issued prior to the disposal of material into the high seas area of the ocean in order to assure that the proposed dumping will not unreasonably degrade or endanger human health, welfare or amenities; or the marine environment, ecological systems or economic potentialities Up until now, this law has resulted in little change in previous dredging procedures. That is, the types of dredging operations and the distances to the disposal area are not significantly different or greater than they were in the past.

However, there are many proposals that all of the dredged materials placed in the ocean be far away from the shorelines. Distances of twenty-five to one hundred miles are often mentioned. If such one-way distances to the disposal areas should be required, then entirely new types of dredging equipment and procedures would have to be developed.

The signficance of the study is that it describes new dredging equipment and procedures that have been tested to date and found successful in meeting the current requirement of pumping materials from hopper dredges to restore or nourish eroded beaches. As time goes by, entirely new dredging procedures, such as the use of submarine dredges, may be developed to meet this need. However, the equipment and procedures discussed in this paper have been tested under a variety of operational conditions and found to provide acceptable environmental and economic results. The requirements to utilize dredged materials for beach restoration and nourishment, and to place polluted materials in diked containment areas, will continue to expand. Therefore, the availability of a proven technique to meet this requirement may be a significant contribution to marine technology.

HYPOTHESES

It is hypothesized that the equipment and procedures discussed in this paper will prove to be suitable, from an

operational and an economical viewpoint, for the excavation, transportation and discharge of dredged materials from the dredging vessel to eroded beaches or to diked areas for the containment of polluted materials.

Also, it is hypothesized that the equipment and procedures discussed in the paper to meet the above need will be suitable for an extended period. That is, the evolution of completely different equipment and procedures will not be required for perhaps twenty to thirty years or more.

DELIMITATIONS

The scope of the paper has been limited to the types of self-propelled, seagoing, hydraulic hopper dredging equipment and procedures that are required to excavate materials from navigation channels or from offshore borrow areas; to transport the materials to unloading sites and to pump the materials from the hoppers of a dredge to either an eroded beach or a containment area for the collection of polluted materials. The operations described do not include the excavation of compact or rock materials that require the use of explosives.

While there are other dredging methods utilized in providing materials for the restoration or nourishment of beaches and various other dredging methods such as the placement of dredged materials into diked containment areas;

they are not discussed at any length in this paper since their efficiency is limited while operating in exposed and ocean waters.

Mechanical dredges, such as the "Sauerman-Bucket" method, in which a dragline bucket is moved along the bottom of the coastal zone from an offshore location to the surf zone through the use of an anchored barge or a piling located offshore and an arrangement of wire cables and sheaves, are not included in the analysis. This type of dredge cannot provide the large production quantities required in many of the navigation and beach-nourishment projects of the country. Other types of mechanical dredges such as the dipper and endless bucket categories are not included in the analysis due to their limited production capabilities and their ineffectiveness while operating in coastal and ocean waters.

Hydraulic pipeline dredges, such as cutterhead, plain suction and dustpans are not included in the analysis. These types of dredges have the potential for great quantities of production. However, because of their hull design and form they are best suited for operation in interior or protected waters rather than in coastal or ocean waters.

Hydraulic sidecasting dredges are not included in the analysis since this type of equipment generally does

not include the capability of storing the excavated materials within the hull; and therefore, cannot be used to transport materials for extended distances.

Pneumatic dredges are not included in the analysis since present day equipment is small and has a limited productive capability. In addition, the experience with this type of equipment is limited in the United States. However, this type of dredging offers some distinct possibilities for usage in beach nourishment and pollution abatement projects. Plans are underway by the U. S. Army, Corps of Engineers, to conduct some evaluational tests of pneumatic equipment to determine its capabilities prior to proceeding with a large scale operational project.[37]

Environmental factors and legislation, which have created the need for new dredging techniques are discussed only in general terms in this paper. Only a few years ago, it was believed by many that dredged materials should never be disposed of in open water. The consensus was that all dredged materials were polluted; and therefore, had to be confined. This is the case when the level of pollution is very great and the materials are located in areas which jeopardize the acquatic population or human health, such as near spawning areas, water supply intakes or in bathing areas. These conditions exist in many sections of the Great Lakes. Therefore, there was a need for legislation which

requires that polluted materials be confined in diked containment areas constructed for this purpose.

In coastal estuaries, where there is a continuing flushing or cleansing action due to tidal variations, it is unusual to find any significant amount of polluted materials on the bottom of the waterways. This is also the case in the offshore zone except for some locations which have been utilized for many years as disposal sites for sewage sludge and other waste products. These factors coupled with the increasing shortage of suitable materials from onshore sites have resulted in a trend to utilize material excavated from the offshore zone to meet the requirements of general construction and beach nourishment. The Inner Continental Shelf Sediment and Structure Survey being conducted by the U. S. Army, Coastal Engineering Research Center, which has been underway since 1965, indicates that large quantities of suitable materials are available in the offshore zone to meet these requirements.[38]

DEFINITION OF TERMS

Definitions of the technical terms utilized in this paper are presented as they relate to dredging activities and especially as they relate to the performance of dredging activities with self-propelled hydraulic hopper dredges:

<u>Agitation</u> -- Disturbance and dislodgement of materials from the bottom of a waterway through the use of a

mechanical excavator or through the use of a hydraulic pump.

Aquatic -- Living or growing in or on the water.

Biota -- The animal and plant life of a region, which is considered as a total ecological entity.

Borrow Area -- An area containing suitable material, which can be excavated and utilized for reclamation or construction purposes; sometimes referred to as borrow pit.

Centrifugal Pump -- Centrifugal is defined as moving or directed away from a center or axis. A centrifugal pump consists of a radial type impeller with two or more vanes, which is rotated within a pump casing or chamber. A mixture of soils and water is drawn into the pump chamber by the pressure differential created by the spinning impeller and forced out of the pump by centrifugal force. A centrifugal pump is something like a water wheel, only working backwards. As the wheel or impeller inside the pump casing is turned, the water or slurry mixture which enters near the hub of the impeller is caught between the blades and hurled outward into the delivery space around the outer edge of the pump casing.

Channel -- A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water; the part of a body of water

deep enough to be used for navigation through an area otherwise too shallow for navigation; a large strait such as the Engineer Channel; the deepest part of a stream, bay or strait through which the main volume of current of water flows, sometimes referred to as a thalweg.

<u>DeLong Pier Barge</u> -- A barge equipped with caissons and jacks, which are utilized to elevate the barge above the surface of the water. In this connection, the barge is utilized as a pier or dock to moor hopper dredges so that the excavated materials in the hoppers can be discharged through a pipeline to a beach or a diked containment area.

<u>Dike</u> -- An embankment usually constructed of soil or rock to prevent floods; or to protect or enclose an area.

<u>Direct Pumpout</u> -- A jargon phrase used in the Corps of Engineers to refer to the unloading of the material from a hopper dredge through a discharge line to a diked containment area or to an eroded beach.

<u>Disposal Site</u> -- The location at which materials are discharged from a dredge.

<u>Downdrift Shoreline</u> -- The shoreline along which the predominant littoral currents flow. Some of the material suspended by these currents accrete along the downdrift shoreline or beach.

<u>Dredging</u> -- The removal of material from underwater.

<u>Dredging Site</u> -- The location at which materials are excavated with a dredge.

Ecology -- The relationships between organisms and their environment; sometimes referred to as bionomics.

Environment -- The complex of social, cultural, physical, and biological conditions affecting the nature of an individual or a community. The combination of external or extrinsic physical conditions that affect and influence the growth and development of organisms.

Equilibrium -- A condition in which all acting influences are cancelled by other influences; resulting in a stable, balanced or unchanging situation or system.

Erosion -- The natural processes, including weathering, dissolution, abrasion, corrosion and transportation, by which earth or soils are removed from any part of the surface of the earth to another location.

Estuary -- The wide or lower portion of a river, where its currents are met and influenced by the tides. An arm of the sea that extends inland to meet the mouth of a river.

Fender -- A wooden, rubber, or any compressible material, placed between a mooring barge or pier and a hopper dredge to reduce the impact of the hopper dredge as it contacts the barge or pier prior to making fast to the barge or pier.

Grain-Size -- The pattern and size of soils produced by the arrangement of constituent particles.

Groin or Groyne -- A rigid structure built out at an angle from a shore to protect the shore from erosion by currents, tides and waves; or to trap sand to make a beach.

Harrow -- An instrument consisting of a heavy steel frame, equipped with teeth or upright disks, used to even or level soils.

Haul Distance -- The distance between the site of the dredging activity and the location at which a hopper dredge disposes of its cargo.

Hectare - A metric unit of area. One hectare is equivalent to 2.47 acres.

Hopper -- A large funnel shaped structure, in which materials such as grain, fuel or construction materials are stored in readiness for quick dispensation and use. In dredging, the hopper sections are utilized to store the excavated materials within the hull of a ship until the materials are disposed of by dumping them through gates in the bottom of the ship, or through pumping the materials from the hopper sections to a site external from the ship.

Hydraulic Dredges -- Dredges which utilize the principle of the centrifugal pump, whereby a vacuum is created on the intake or suction side of the pump. Material is dislodged from the bottom of the waterway because of the pressure differential between that inside the pump and the

ambient water head. The material is suspended in the form of a slurry and forced through the pump and piping system to a designated disposal location.

Hydraulic Hopper Dredge -- A ship, with the molded hull and lines of a seagoing vessel, equipped with propulsion machinery, dredge pumps, suction pipes and other special apparatus and machinery required to hydraulically excavate material from a channel bottom or ocean bed, discharge the material into hoppers within the vessel, transport the material to a designated disposal site and discharge the material either through dumping in open water or by discharging the material through a pipeline to a beach or a diked containment area.

Impeller -- A rotor, or series of rotor blades, used to force gas or liquids through a pump under pressure.

Jetty -- A pier or rock structure projecting into a body of water to influence the currents or tides and to protect a harbor or shoreline.

Kip -- A 1,000 pound unit of weight or force.

Littoral Currents -- Currents which flow generally parallel to the shoreline, and which usually flow in a predominant direction.

Moor -- To secure or make fast a vessel by means of cables, anchors, caissons, spuds or other contrivances.

Mooring Barge -- A barge utilized to moor a hopper dredge so that the excavated materials in the hoppers of the vessel can be discharged through a pipeline.

Nutrient -- Something that is assimilated by a living organism that results in nourishment and growth.

Offshore Zone -- An open water area in which the depths of water are great; deep water areas near the coastline, with depths in excess of thirty feet.

Photic -- The upper zone or region of a body of water, into which sunlight penetrates.

Pollution -- The contamination of soil, water, or the atmosphere by the discharge of gaseous, chemical, organic or any noxious waste.

Prism -- The geometric shape of a channel, formed by the bottom depth and width desired, and the specified side slopes or angles.

Pristine -- Remaining in a pure state. Pertaining to or typical of the earliest time or condition; primitive or original.

Roadstead -- A sheltered, offshore anchorage area for ships.

Scow -- A large flat-bottomed boat or barge used for transporting materials excavated by a dredge.

Shoal -- A place in a body of a waterway where the water is especially shallow. An elevation of the bottom of a body of water, constituting a hazard to navigation.

Sludge -- The precipitated solid matter produced by water and sewage treatment processes -- a muddy or slushy mass, deposit or sediment.

Slurry -- A thin mixture of a liquid, comprised mostly of water. In dredging operations, the solids or soil materials that pass through a centrifugal pump comprise about ten to twenty-five percent of the total flow. The remainder of the mixture is water.

Spud or Caisson -- A metal pipe or structural member which is suspended vertically through guide sleeves or wells in the hull of a dredge or barge. When lowered into the bottom of a waterway, spuds serve as an anchoring or maneuvering device. In the case of DeLong Pier Barges, the barges can be elevated above the water surface using jacking gear on the spuds.

Subaqueous -- Found or occurring underwater.

Suction -- An atmospheric force that causes a fluid or a solid to be drawn into an interior space; or to adhere to a surface because of the difference between the external and internal pressures.

Strand -- The land bordering a body of water; a beach, especially the area between the low and high tide water levels.

Toxic -- Harmful, poisonous, and sometimes deadly gases, liquids and solids.

Turbidity -- A condition in which sediments or particles are suspended in a body of water.

Vacuum -- The absence of matter or a space relatively empty of matter. The ancients tried to explain the fact that a suction pump will not raise water more than thirty-three feet by saying that "nature abhors a vacuum."[39]

Waterway -- A river, channel, canal, lake, or other body of water used for travel, or for the transportation of commodities; sometimes referred to as a watercourse.

METHODOLOGY

The survey method or descriptive study approach is utilized. This method was selected because the study will summarize the facts and circumstances associated with three test operations involving the use of self-propelled, hydraulic hopper dredges. Each test was conducted to determine the operational, environmental and economic feasibility of excavating material with a hopper dredge, transportation of the material to a mooring barge located in open water, and the discharge, through centrifugal pumps and a pipeline, of the excavated material to nourish or

restore eroded beaches. The operational and economic information derived from such tests at Sea Girt, New Jersey; Jacksonville, Florida; and Virginia Beach, Virginia are herein presented and evaluated. The wind, wave and sea conditions encountered are described since these were key factors to be dealt with while operating in the offshore zone. In addition, the feasibility of this technique for long term use in other areas is described. All of the test operations were conducted utilizing equipment developed by the U. S. Army, Corps of Engineers. In addition, all of the data relating to the usage of hopper dredges utilized in this study were extracted from the records maintained in the Civil Works Directorate of the U. S. Army, Corps of Engineers, Washington, D. C.

ORGANIZATION OF SUCCEEDING CHAPTERS

The study has been organized to meet the criteria contained in the "Student Handbook, Fifth Edition," published by Heed University in February, 1978, and the "Form and Style Manual, Fourth Edition," published by Houghton Mifflin Company, 1974.

Chapter 2 includes a review of the literature relating to dredging, marine construction and beach nourishment techniques.

The methodology for preparing this descriptive study is described in Chapter 3.

Chapter 4 includes a description and summary of the operational, environmental and economic factors associated with three tests involving the use of hopper dredges to excavate materials from the offshore zone, the transportation of the materials to a site near the strand and the discharge of the materials to eroded beaches.

An analysis and comparison of the relative success of each of the test operations is presented in Chapter 5.

The findings, conclusions and recommendations of the study are included in Chapter 6.

SUMMARY

Because dredging is an activity known to a relatively small number of people, Chapter 1 includes definitions of dredging and a brief resume' of historical events which were significant in the evolution of the dredging process. This chapter also includes a summary of the objectives of dredging and of the environmental factors which should be considered, when any dredging work is planned. In addition, there is a statement of the problems addressed in the study, the purpose and significance of the study, the hypotheses, delimitations, definition of terms and the description of methodology utilized in the preparation of the study.

Most of the books and technical papers written on dredging address specific technical operations or problems.[40] In most cases very little attention or effort has been directed toward providing the reader with an overall view or with historical or descriptive information. This is unfortunate, since there is a need to describe dredging activities in such a way that the studies will be interesting and useful to those people in other disciplines. For this reason, considerable background material and a general overview have been included in this chapter.

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Chapter 2

REVIEW OF RELATED LITERATURE

A review of the literature revealed that the number of books, periodicals, dissertations, theses and technical papers published on dredging is limited. The volume of background material has increased significantly since World War II, with a particular increase since the 1960's. An impetus to the increased number of studies has been the organization of professional societies and associations dedicated to the advancement of dredging technology. In referring to the literature on dredging activities Saucier (1976) indicated:

> I was very surprised recently when I made a tabulation (in terms of date of publication) of the reasonably widely available technical literature on the subject of the environmental effects of dredging. I found that more than 98 percent of the total known literature is less than 10 years old and more than 80 percent is less than 5 years old. Also, as we probably all realize, the literature is not abundant. But I'm sure most of you will be surprised with my estimate that, with the publication of the Proceedings of this conference, the total number of articles in the international literature will be increased by nearly 5 percent.[1]

BACKGROUND

For many years, dredging was considered to be an art rather than a science. And indeed in large measure it

was once so. As a result, methods and procedures that were successful were treated as trade secrets and discussed with only those people within a company or corporation that were involved in the performance of dredging work.[2] And this viewpoint is still commonplace in a large number of dredging companies. It is difficult to comprehend how it has been possible to inhibit the exchange of information until one reflects on the circumstances in which the dredging industry operates. Even today there are only a small number of people involved in the industry, when it is compared with other types of construction activities. Brouwer (1974) indicated that the international dredging industry included over 1,000 dredge-owning organizations, operated over 6,000 pieces of dredge equipment, employed about 400,000 people and that during the period of 1965 to 1970 the annual turnover varied between 5 and 10 billion U. S. dollars.[3]

Moreover, dredging operations are conducted in waterways and are accessible only through the use of launches, which makes it difficult or impossible for the casual observer to see what is taking place. In many cases, the operations are performed in offshore locations, entirely out of sight of land. Under these circumstances, many projects are completed without the local population being aware of the operation. The limited public awareness of dredging activities and their importance to the nation were referred to by Graves (1976):

> Dredging has been vital to world commerce for hundreds of years. Yet, until recently, it was the concern of relatively few people. Then it began to receive widespread attention, not because of its vital importance to commerce, but because of undesirable side effects. Those of us most concerned with dredging have had to mobilize our forces in order to reexamine how we go about this important work. Already this effort has resulted in very substantial improvement, with much mpre promised in the future.[4]

There has been a concerted effort during the past ten years or so to improve the degree of professionalism in the dredging industry. However, these efforts have been limited to only a few organizations, such as the World Dredging Association, the Permanent International Association of Navigation Congresses and the British Hydraulic Research Association. Consequently, the great majority of literature which is referred to in this study was derived from these sources, which sponsor seminars and conferences on dredging activities.

NEED FOR PROFESSIONALISM

Tibby (1967) referred to the need for an increase in professionalism in the dredging industry by indicating that the scope and complexity of dredging activities had increased dramatically in recent years. He correlated the growth of the dredging industry with the need for an advanced level of education as follows:

> In this expansion, your reliance on the skilled personnel and the research results provided by universities also has increased. As we develop the competent

> engineers, marine scientists, and the other professional people you need, the basic and common knowledge of engineering, geology, oceanography and even business management can be taught in our schools. To some extent we can indoctrinate our students in the peculiarities of the environment in which they will expect to work, but beyond that point the acquisition of special skills and detailed knowledge of their applications come only through long and hard experience in the field. In this situation, the academic community and the practitioners of dredging formerly had rather little in common, at least as far as your industry's operations were concerned. There was some limited interplay through the utilization of academic brains in special circumstances, but dredging per se, or even general marine construction, had little impact either on the institutes for ocean sciences or on the faculties of engineering schools.[5]

In referring to the quantity and quality of literature written on dredging, Huston (1968) stated:

> The development of the dredge happened through random trial and error, rather than by plan. The dredging pioneers were interested in the practical aspects of making money, not academics. They put into writing little of what they did. . . . There is a dearth of published, practical and useful dredging information. On the premise that a profession is known by its literature, dredging might well be eliminated. Its literature is almost nil . . . . Because of the dredge's wide usage, great output, ease of spoil disposal, efficiency and economy, one would think a profuse amount of descriptive information would be available. Not so. Less has been written intelligently about the dredge than any other piece of excavating equipment known to man. Resultingly, only those that work directly with the dredge obtain anything more than a passing knowledge of its operation or its capabilities. Others have little opportunity to learn.[6]

SHORTAGE OF SAND AND GRAVEL

Michel (1967) indicated that the encroachment onto our beaches by man and his structures had created the need

for more beach areas, and at the same time had created a situation that tends to destroy the existing beaches.

Michel, in his presentation "Offshore Dredging for Beach Nourishment, Challenge of the Future," highlighted the need to obtain construction materials from the offshore zone:

> Formerly, material for beach nourishment was available from inland waters such as bays and channels. These supplies have been seriously depleted. There is also considerable pressure from conservation groups to prevent the removal of these sources. This leaves only the open sea off the beach for dredging. Economical exploitation of this source requires a new concept in systems and hardware . . . . Offshore dredging with conventional equipment fails economically, due to time lost when waves are too high for operation due to the need for periodic demobilization of the entire system when storms are imminent.[7]

From the standpoint of the supply of materials suitable for construction purposes and beach nourishment, the offshore zone holds the greatest potential. While this fact is well known today, it is interesting to note that scientists were forecasting this situation many years ago. For example, Mero indicated that sand and gravel had been traditionally excavated from pits near the cities, but that zoning ordinances and conservation considerations were contributing to the need to locate alternate sources for these materials. Mero (1967) described an alternate source:

> The offshore areas, of course, are well supplied with sand and gravel deposits, and in some areas, notably off England, exploitation of these deposits has been initiated. Off the northeast coast of New Jersey an extensive deposit of this material has recently been discovered (Schlee, 1964) which could easily supply the New York area at very reasonable costs. Because much

> of the world's population is concentrating in the seacoast areas, the offshore gravel deposits will become increasingly important sources of this material . . . . While onshore beaches have been mined for many years, it is only recently that the great potential of the offshore areas has been realized. During the Ice Ages, sea level was appreciably lowered as the ocean water was transferred to the continental glaciers. Because of the cyclic nature of the Ice Ages and the intervening warm periods, a series of beaches were formed in areas offshore of the present beach deposits. With recently developed sonic devices, it is not difficult to locate and delineate these submerged beaches . . . . The ocean floor sediments possess many advantages over land deposits when being considered as a material to mine. They are . . . widely distributed near most markets, and they are available to all on an equal basis. In addition, they are fine-grained, unconsolidated and in a water atmosphere which makes the use of automated hydraulic systems for recovery practical.[8]

Goodier (1967) indicated that extrapolations of geologic information from land surveys, combined with federal and private surveys of the subaqueous land mass, have provided physical evidence that there is considerable mineral potential in and on the ocean floor. The mineral deposits of the continental shelf are generally comparable in quantity and quality to those on the adjacent land mass. And in most cases the mineral potential has been enriched by deposition and years of coastal erosion. Even wind blown particles, transported offshore to settle in the ocean, can constitute a considerable mineral reserve when viewed as an accumulation through millions of years.

Goodier cited the need for mining offshore:

> A few pioneers have worked diligently, in the shadow of a massive aerospace program, to alert both the government and industry to this marine source of raw

> material and wealth. It is only within the last five years that more than a passive interest has been generated toward the possibility of exploiting the minerals of the ocean environment. The dredging industry has been one of the slowest to accept the fact that its talents and equipment will be of foremost importance in recovering the minerals from their seafloor location. Organizations with the equipment, personnel and technical experience to dredge shipping channels and to reclaim land with the spoil material can mine the ocean . . . . The suction hopper dredge presents a most attractive picture to the ocean mining industry. The elimination of costly small craft, tugs and transportation barges and the advantages of self propulsion greatly enchance the use of these vessels. The capability to head into rough seas while simultaneously transporting the recovered material in its own storage hoppers is unique to this type of dredge.[9]

The demand for sand and gravel in the United States is great and can be related most directly to the population growth and rate of industralization or urbanization. At present, the demand for aggregates is being served for the most part by onshore quarries using relatively simple technology. However, a problem of supply is arising on a national basis and is now in existence in several major coastal metropolitan areas. Such areas consume vast quantities of mineral aggregates in the construction of commercial and residential buildings, factories, bridges, streets, highways, storage areas and airports. The trend to force operators of quarries and borrow areas farther from the cities and metropolitan areas is causing a rapid increase in the cost of aggregates for construction purposes. In addition, even in locations which are remote from

metropolitan areas there are environmental constraints and objections to large scale excavation projects. Thus, there is an increasing need to obtain aggregate materials from the offshore zone. While there are some environmental factors to be considered in the extraction of aggregates from this area, they are generally less stringent than those associated with the operation of quarries on land. The idea of mining sand and gravel from the continental shelf is not novel. England, The Netherlands and Japan have developed commercial offshore industries in this field. As the existing sand and gravel sources in the United States are depleted and the cost of transportation from the quarries continues to increase the sea must meet our aggregate demands. Davenport (1971) stated:

> Demand from coastal cities for mineral aggregates is large and growing. It is likely that within this decade, industry will turn seaward for many commodities including sand and gravel . . . . An opportunity exists at this time for creative and effective management of a new resource which can promote a healthy industry if environmental protection can be provided adequately . . . . As onshore producers are forced farther from their markets, the cities, delivered prices of sand and gravel may continue to rise reflecting higher transportation charges. A hypothetical case study using a large hopper dredge for a long term offshore mining operation is presented. This model indicates that such an operation could be economically feasible, given certain assumptions.[10]

Goodier (1971) indicated that the coastal states of the United States are experiencing a shortage of sand and gravel and that presently available reserves could be

depleted in about sixteen years. He forecasted an immediate need to determine the availability, quality and quantity of offshore sand and gravel deposits and to develop technical capabilities for the recovery of such deposits without detrimentally disturbing the natural environment. Goodier's position on this matter is as follows:

> It is not a case of where, but when offshore sand and gravel dredging will commence. The New England states should commence preparing for the event with intelligent legislation, the development of strict environmental controls, a series of offshore surveys that will determine the distribution, quantity and quality of available sand and gravel deposits in state-owned submerged land . . .[11]

Baram and Lee (1975) indicated that the coastal zone of the United States provides many valuable economic and environmental resources and that among the uses of the coastal zone are transportation, recreation, fishing, waste disposal, power production and mineral resources extraction. They indicated that interest in the offshore mining of sand and gravel has been spurred by several factors. The first factor mentioned was population growth, with its attendant needs for increased quantities of aggregates resources. The second factor was the rising standard of living, which is bringing about increased automotive and air travel, the development of suburbia, greater per capita construction and increased capital improvement expenditures. A third factor referred to was the remarkable rise in the demand for outdoor recreation and related facilities, especially those that are water

and beach related. A fourth factor is the increasing need for offshore facilities such as nuclear power plants, petroleum off-loading facilities and airport construction. In relation to the increasing need to obtain sand and gravel from the offshore zone, Baram and Lee stated:

> As demands for sand and gravel increase, there is the danger of depleting the best and closest deposits of these nonrenewable resources. Two other factors promote scarcity: (1) zoning which prohibits the onshore mining of proven sand and gravel deposits, as a result of sprawling urbanization, particularly in the coastal zone; (2) state and local legislation and private litigation against the "nuisance" and environmentally-harmful aspects of pits, quarries, processing plants and truck fleets. These and other conditions have brought about scarcity and rising prices, especially in metropolitan areas along the coasts of the United States.[12]

Herbich (1975) indicated that in recent years it has become increasingly more difficult to find the right type of sand in sufficient quantities, as well as at a reasonable cost for beach replenishment purposes. Herbich stated:

> Since land deposits of sand may not be available or within an economically-short distance from the beach and since the sediment from bays and estuaries may not be suitable or available because of the environmental considerations, the coastal engineers have started looking at the possibility of tapping offshore sand deposits as a source of sand for beach replenishment or nourishment.[13]

The primary factors which limit the use of sand deposits in bay and laguna areas for beach fill and in some instances for other purposes were described by Watts (1974):

> Two important factors are that, first, in many coastal segments a more careful evaluation of materials composing the subbottom in bays and lagoons indicate the size characteristics are not suitable for beach fill and, secondly, sediments composing the bottom of these marginal water bodies may be very important to cycles of marine life. These two factors have focused attention towards use of offshore bottom deposits for beach fill . . . . In view of the increased interest and need for utilizing offshore borrow for beach fill, the U. S. Army, Corps of Engineers initiated a program in 1965 to define the quality and extent of offshore sediment deposits . . . This program involves selected layouts of seismic geophysical coverage supplemented by core borings for the zone between the 15 and 100 foot depth contours. These collected data are analyzed with the objective of delineating the physical characteristics and extent of material available for beach fill purposes.[14]

The need to obtain construction materials from the offshore zone was discussed by Pohlke (1974):

> In recent years, offshore gravel dredging has increasingly gained importance in Europe. Indications are that this importance will continue to increase rapidly. The unused offshore reserves are great and, on the other hand, recovery of inland deposits becomes more difficult for reasons of environmental protection.[15]

The international shortage of sand and gravel was discussed by Turner (1974):

> The demand for sand and gravel continues to increase throughout the world. Inland sources of this material are diminishing through depletion and environmental restrictions, forcing offshore procurement. Existing equipment to mine sand offshore is expensive to purchase and operate, thereby creating a demand for more efficient and less costly offshore dredges.[16]

The shortage of sand and gravel in the northern section of Canada was referred to by Williams (1976):

> The problem in our Western Artic, in addition to the sensitive tundra and permafrost, is the shortage of

> natural materials such as sand and gravel. The most readily available materials are under water, and in most cases, under a substantial layer of soft overburden. We will have to dredge for it.[17]

EQUIPMENT REQUIREMENTS

Michel (1967) indicated that offshore dredging involves four tasks: excavating the material, loading it into a means of transport, getting it on or near the shoreline and discharging it at the desired location. He also indicated that sometimes more than one, or even all of these tasks can be accomplished by a single piece of equipment such as a hopper dredge. Michel expressed the following viewpoint.

> It is safe to conclude that progress is likely in the field of offshore dredging. It would be nice to foresee in the near future an army of bottom crawling earth movers, moving like a column of ants from offshore spoil areas to nourish a beach, but honesty precludes it.[18]

McManus (1967) indicated that the demand for industrial sites near the sea or near rivers is constantly growing as industries, dependent upon water for cooling or transport, continue to expand. It was also postulated by McManus that reclamation of low-lying areas or shallow bays is a more attractive economic proposition than ever before. McManus presented the view that:

> The types of equipment indicated as being most suitable for reclamation projects were considered to be the specially designed barge emptying plant; the self-unloading hopper dredge; and the cutter suction dredge.[19]

The need for improved dredging equipment was highlighted by P. J. van Lunteren (1968) who indicated that keeping pace with the rapid developments in trade and transport in the post-war period has meant building new harbors, enlarging existing ones and widening and deepening rivers and other waterways. He also indicated that perhaps the most spectacular development of all has been in the tanker field. At the end of the war, a vessel of 25,000 tons was considered large, but now ships with a quarter of a million tons deadweight are becoming commonplace.

Addressing the need to provide facilities for new and large vessels, van Lunteren stated:

> There is nothing to beat a trailing suction dredger for speed and efficiency in the kind of operations involved: it is highly maneuverable and has a high production rate; more important still, its presence in a busy waterway does not hamper shipping, and it can continue to operate in open water in very poor weather.[20]

The hydraulic suction dredge is considered by many to be the most effective means of excavating materials from the offshore zone. Herbich (1968) presented the following view:

> It is agreed that probably the most economical way of recovering minerals from the ocean floor is by means of suction dredging. It is anticipated that mineral recovery will start first from the continental shelves and then, as the methods are perfected, it will be possible to dredge from greater depths.[21]

The forecast of Dr. Herbich has proved to be correct. Up until recently the largest hopper dredges were equipped to excavate to a maximum depth of fifty-five to sixty feet and

production rates at these depths were very low. However, with the advent of the submerged type of centrifugal dredge pump, material can be excavated efficiently from much greater depths. For example, two seagoing hopper dredges currently under design by the U. S. Army, Corps of Engineers will be able to maintain a production rate at a depth of eighty feet that previously was achieved at a depth of about twenty-five feet.

Andreae (1971) indicated that, during the past fifteen years, the development of dredging plant had evolved in a reasonable relationship to the development of new ports and harbors and the enlargement and improvement of existing ports and harbors. He indicated that during this period a "technical revolution" occurred in the dredging field to meet the demands of large scale navigation projects. In discussing the changes in the nature of dredging equipment, Andreae said:

> . . . The growth of the trailer suction hopper dredge fleet proves to be amazing, not only in capacity, in this case indicated by the contents of the hopper well, but also in number . . . . With the expansion of ports along rivers and the increasing approach channels in connection with the larger tankers, demands arose for a seaworthy dredger with propulsion, to enable dredging in rather rough water and in busy ship channels, where conventional dredgers are obstacles to the traffic. The dredged material, settled in the hopper well, can be dumped either at any place in the sea or in front of a reclamation dredger and in some cases the trailer dredger is also able to unload herself dishcarging ashore. The very large quantities to be dredged from the approach channels of oil ports nowadays

> have stimulated the construction of super trailers with more than 10,000 cubic meters hopper contents. . . . From the previous information it can be concluded that with the fast increasing capacity of the plant, the dredging industry can well play an important role in offshore reclamation projects.[22]

O'Neill (1972) indicated that we are being forced to dig deeper to obtain new sources of mineral and other raw materials and to deepen waterways for the acceptance of the ocean-going vessels that are being built larger and larger. He also indicated that moving to areas with greater depths is also required by claims of real or imagined damage to the coastlines or fishing industries. For example, in England the sand and gravel industry has moved farther to sea. With regard to the need for new equipment to meet this requirement, O'Neill described a proposed dredge:

> We believe that this dredge, as conceived, will answer the demands for efficiently and economically digging to greater depths than are currently possible. Furthermore, this proposed dredge contains greater feasibility for adapting to differing conditions, whether onshore or offshore. With suitable ground tackle, the effect of tides, wave action, swells, and winds would be effectively curtailed.[23]

Addressing the need for improving dredging equipment and procedures to meet existing and evolving legislation relative to the protection of the environment, Rhodes (1972) indicated that thinking in terms of larger and more powerful conventional cutterhead pipeline dredges or hopper dredges will not provide a solution to the problem because there are practical limits to the size of dredges and the lengths of

pipelines. Rhodes presented the need for some important improvements:

> New concepts are needed to transport materials long distances at economical costs. In some instances bottom dumping or self-unloading scows may be needed. Practical uses for the materials might be further developed, such as for beach nourishment or providing needed fill materials for construction activities. Along the Texas Coast some of the material can possibly be used in the construction of hurricane protection levees. These are matters which I feel must be actively pursued by both the Corps of Engineers and the dredging industry.[24]

Turner (1975) indicated that most of the major dredges built within the coming decade will be equipped with submerged dredge pumps, and many of the existing dredges will be modified to include them. The reasons given for this prediction were: First, deeper draft vessels, with current requirements for 82' channels and with projected channel depths 100' or greater; Second, ecological limitations on borrow pits forcing them to deeper depths; and Third, the requirement to excavate hard minerals from 150' depths and greater. Turner also indicated that a submerged pump can more than double the maximum output of a dredge at a digging depth of 50' and quadruple the output at a digging depth of 82'. To demonstrate the reason for this variation Turner stated:

> With the dredge pump at water level, water will rise to the pump centerline under static conditions. Under flow conditions, however, the only force to overcome the suction line losses is nature's barometric pressure. The dredge pump evacuates its housing and creates a discharge pressure, but only

> when it is fed by nature's barometric pump at a rate that prevents cavitation. The largest single suction loss to be overcome by barometric pressure is caused by the weight of the solids in the slurry. If we assume an optimum slurry SG of 1.5, then the head needed to lift the solids is the .5 (subtracting 1.0 for water) times the digging depth. At 10' digging depth it is 5' of head, but at 50' digging depth, it is 25' of head. Since nature only provides 34' of head, one can see that compromises must be made at deeper depths . . . .[25]

Krizek and Lai (1975) indicated that the hopper dredging process serves to reduce the degree of pollution in the excavation of materials from waterways. They also indicated that the reduction in the pollution level should be considered when determining whether the materials should be placed in diked containment areas which result in a cost many times that of the open water disposal method. Krizek and Lai stated:

> However, during the dredging and disposal operation the dredge spoil is generally mixed several times with large quantities of ambient water, and the excess water is subsequently returned to the river or lake. For example, in the case of a hopper dredge, the spoil is combined with considerable amounts of water as it is removed from the bottom of the harbor and deposited in the hopper of the dredge, and, as the solids settle, the excess water sometimes overflows the dredge. Then, when the dredge pumps the spoil into the disposal area, the solids are again mixed with large quantities of ambient water, and, after sufficient retention time to allow the majority of the solids to settle out of suspension, the excess water exits the disposal area through an overflow weir. On both of these occasions there is a tendency for elutriation to take place, and the concentration of pollutants may vary considerably at the various stages.[26]

The correlation between the size of ships and the need for improved dredging equipment was highlighted by Brouwer (1974):

> After 1950 we saw a tremendous upsurge in your industry. Diesel engines became widely used. Reclamation of inundated areas in Holland and recovery of flooded coastal areas around the North Sea after storms in 1953 and 1956 provided the incentive of urgency to further evolution in the industry. In addition, during the last 10-20 years, formidable industrial development took place while deep-draught supertankers (VLCC's) became the main vessels for long range transportation of crude oil. Deep sea ports had to be constructed, and vast new industrial areas and residential districts near large towns had to be reclaimed involving construction of roads, railway lines and airports. All these became in major part feasible, technically as well as economically, through tremendous extension and modification of the dredging fleet; the introduction of super trailing suction hopper dredgers played an important role in tackling large offshore dredging projects as well.[27]

Changes in the design of dredging equipment to meet changing operational and environmental conditions were described by Murden and Cable (1974):

> Our concern for the most favorable project economics and the improvement of water quality in navigable waters requiring dredging operations prompted our design of the capability to pump the materials from the bins of some of our hopper dredges as early as 1953. In those cases, where available and suitable disposal areas are remote from the dredging sites, our design had to provide the capability for the hopper dredges to pump through a discharge line with a maximum length of 20,000 feet, without utilizing a booster pump.[28]

A design improvement required to provide efficient results when excavating materials from depths of ninety-three feet was described by Ofuji and Koyo (1974):

> Today ocean development is being studied to help make possible more effective utilization of the ocean, and plans for the construction of offshore warehouses, cities, and man-made islands or huge bridges, etc., are being advanced seriously. In parallel with the construction of mammoth marine structures, ocean

> engineering projects are gradually moving farther from coastal areas, resulting in an increase in the dredging depths for cutter suction dredgers. Dredging at great sea depths will entail the necessity to boost the suction head of the dredging pump. Should this be achieved by means of the ejector, and should this report serve as reference in such an event, the author's efforts will be amply rewarded.[29]

Congressional interest in the construction of new dredges by the Corps of Engineers and the dredging industry was referred to by Murden and Goodier (1976):

> . . . it appears that the Congress intends to authorize the Corps to proceed with the design of 3 new hopper dredges and to initiate construction of a shallow draft hopper dredge during this next fiscal year. At the same time, the Congress and the Corps continue to encourage Industry to enter the hopper dredge field and to maintain a predominant role in meeting the national dredging requirements.[30]

BEACH NOURISHMENT

The first experiment utilizing a hopper dredge as the means of pumping dredged materials to nourish an eroded beach in the United States was conducted in 1966 at Sea Girt, New Jersey. Material to nourish the beach was obtained from a borrow area located about two miles offshore of the beach in the Atlantic Ocean. A mooring barge, anchored about 2,000 feet from the surf, served as the means for berthing the hopper dredge and for coupling the hopper dredge piping system to the submerged pipeline leading to the shoreline.

About 250,000 cubic yards, consisting of fifty-two hopper dredge loads were pumped to the beach through a pipeline length ranging from 3,800 to 4,000 feet. The hopper

dredge was utilized only nineteen days. However, considerable time was spent in the placement of the mooring barge and the submerged and shoreline piping system prior to the actual pumping of the material.

Mauriello (1967) summarized the results of the test:

> Fundamentally, the Corps of Engineers beach nourishment experiment at Sea Girt, New Jersey, served to demonstrate the capability of a suitably equipped seagoing hopper dredge to pump sand onto an ocean beach from an offshore mooring, thereby further enhancing the versatility and usefulness of this type of hydraulic dredging plant. However, future applications of this technique for the economical rehabilitation of ocean beaches, to provide erosion control and shore protection, will require further study by the Corps of Engineers on an individual project basis as well as from the standpoint of overall coastal requirements . . . . The flexible connection between the floating mooring and the submerged pipeline was the major source of difficulties during the operations. While the experimental assembly used proved deficient, it is felt that the operating experience gained with this equipment in an ocean environment provides sufficient guidance for the future development of a suitable rugged and reliable link.[31]

One of the early and successful beach nourishment projects utilizing the hopper type of dredge was at Copacabana Beach, Rio de Janeiro, Brazil. In this project, material was excavated from an offshore source about two miles from the strand, transported to the bay and dumped through the hopper gates of the ship into depths ranging from twelve to eighteen feet. The only reference to this project that could be located was by Nicoletti (1971),[32] which dealt primarily with the use of cutterhead pipeline dredges. However, Nicoletti indicated that in all areas

except one along the beach that the desired width of strand had been achieved and that the hopper dredge portion of the work was extended to make up for the deficiency.

Hopman (1972) indicated that, historically, the Corps in the Northwest has used hopper dredges to remove sediment from inlets and disposed of it at sea in pre-determined areas which are usually within two miles of the shoreline. He also indicated that some of the dredged materials are disposed of in strategic locations within the estuary to contain the resource but that this procedure was opposed by some environmental groups advocating that all dredged sands be hauled long distances to sea and dumped beyond the continental shelf or placed on uplands. Addressing the beneficial usage of these materials Hopman reasoned:

> Meanwhile, beaches adjacent to the coastal inlets are being starved as a result of the present jetty systems, loss of sand due to severe storms, or long periods of loss by littoral drift. In addition to these losses, dams, reservoirs, river controls, and dredging which places sediments above the high water line or removes it for commercial use, remove sand from the system even though it is a diminutive amount. Therefore, it is suggested that clean, unpolluted sands such as are present in most of the Pacific Northwest's coastal inlets should not be wasted forever but must be kept in the circulation system.[33]

Mohr (1975) indicated that extensive beach erosion problems exist along many of the beaches of the United States and that groins and bulkhead structures installed as beach protective devices have only been partially

successful. He indicated that the utilization of sand for beach nourishment from dwindling inland sources has become increasingly difficult and costly and that there exists an ever increasing need for an alternate and more economical long range solution. In addressing a possible solution to the problem Mohr stated:

> Such a solution is to regain sand lost to the sea. Unfortunately, the nature of this operation has proved hazardous and costly in the past. While several new designs are presently in various stages of development, the modern hopper dredge with pumpout capability is an available tool to achieve beach replenishment operations. This type of plant. owned by the United States Army, Corps of Engineers, has been engaged in beach nourishment test and evaluation operations, and is suitable for large scale, long duration assignments. . . . To establish the location, characteristics, and extent of sand deposits in the oceans' nearshore zone which could be utilized for beach replenishment projects, the Coastal Engineering Research Center of the Corps of Engineers, initiated a sand inventory program during 1964. Preliminary analysis of data procured to date indicates the existence of suitable sand deposits between the 15 and 100 feet depth contour within 10 miles of any selected location on the shore. The concentrated sand deposits vary in thickness with some in excess of 25 feet.[34]

In reviewing the circumstances relating to the use of materials excavated from the offshore zone for beach nourishment in New Jersey, California and two locations in Florida, Watts (1974) indicated that:

> The . . . projects accomplished to date by hydraulic dredge plant operating in an exposed ocean environment clearly demonstrate this type operation is feasible and practicable. The question is therefore not of feasibility but a matter of refinement of economics with regard to modification of existing plant and operations and/or development of new plant to meet requirements . . . . The cases cited suggest that

disturbance of bottom materials temporarily created attraction for fish presumably seeking food. It is also obvious the surface area of the dredge cut temporarily eliminates marine life therein and the precise length of time for the bottom surface of the dredge cut to return to normal marine activity is yet to be established; however, preliminary collected behavioral data also suggest this is a relatively short length of time.[35]

The extent of the international beach erosion problem was referred to by Turner (1974):

> As the population density of other continents increases, unquestionably offshore mining will assume greater importance. In the United States, for example, a study has been made of the nation's shorelines, and it is estimated that approximately $2 billion worth of shoreline restoration and protection must be accomplished within the next few years to avoid further critical deterioration of this great natural resource. Most of this work will involve offshore dredges to restore the beaches to their original size and beauty with the original material, sand. If other nations were to conduct a similar study, a similar need would probably be disclosed. I suggest, therefore, that offshore dredging will inevitably become a major industry around the world, and those operators who have efficient, low unit cost equipment with which to accomplish this mining will find themselves in a booming market.[36]

EARLY DREDGE DESIGN FEATURES

It is rare that one can think of something that has not been conceived before, and such is the case with the design for the pumping of material from the hoppers of a dredge through a pipeline to a disposal area. Scheffauer (1954) pointed out that this concept was available many years ago:

> Between 1910 and 1920, the BASECON, COMSTOCK, SAN PABLO, MICHIE, MINQUAS and NEW ORLEANS were constructed . . . . The COMSTOCK and SAN PABLO were practically identical, but the SAN PABLO was unique in that it could pump the material in its hoppers ashore and also because in lieu of fixed dragarm trunnions, it had combined elbow ball-joints mounted in slide plates which moved vertically in guides on the ships sides. This slide arrangement permitted raising the entire dragarm from the operating position to the main deck level when traveling to and from the dump ground or when berthing the dredge.[37]

It must be conjectured that the capability of the SAN PABLO to pump the material from its hoppers was installed based on economic factors, since environmental considerations in those days were minimal. It does not seem possible that the unique and visionary design parameters, which were available in prototype form in 1916, were not included on any other hopper dredges until many years later. The sliding trunnion-dragarm feature, which permits the hoisting and storage of the suction piping assembly in saddles on the main deck of a hopper dredge appeared again in the U. S. Army, Corps of Engineers, hopper dredge, LYMAN, which was built in 1945. The capability to pump materials from the hoppers of a seagoing hopper dredge did not surface until 1963, when this feature was installed on the U. S. Army, Corps of Engineers, hopper dredge, COMBER, some forty-seven years after the construction of the SAN PABLO. Both of these design parameters were quickly adopted by the hopper dredge industry and were in widespread international usage only a short time after they were installed on the Corps of

Engineers hopper dredges. From the standpoint of economics this latter feature, which has become known as the "direct pumpashore" or sometimes the "direct pumpout capability" has the potential for significant cost savings. For example, for many years the materials dredged from the navigation-channel of the Delaware River leading to Philadelphia, Pennsylvania, were dumped from the hoppers of dredges into open water areas outside the channel. The average annual yardage removed from the navigation channel of the Delaware River was about twenty-two million cubic yards during the long period that this procedure was followed. Shortly after the modification of the COMBER in 1963 and the utilization of the direct pumpout capability to place the dredged materials in diked containment areas, there was a noticeable reduction in the average annual dredging workload. Within ten to twelve years, the average annual workload dropped to about ten million cubic yards and has remained at this level; a reduction of fifty-five percent. Aside from the dramatic decrease in the cost of performing this work, the direct pumpout procedure has provided a significant environmental benefit. Some years ago it was found that the bottom materials in the Delaware River were polluted and that the confinement of the materials in diked areas was contributing to the improvement of the water quality in the river. Oddly enough, considerably more attention and praise has resulted

from the determination that the direct pumpout procedure provides environmental benefits than from the tremendous reduction in the annual cost of the operation.

The early use of dredges in the United States and the construction of the first hopper dredge were described by Bastian (1976):

> Dredging in the United States pre-dates 1800. As the country grew, so did the number of ports as well as the size of ships. By 1830, dredging was being done on the Atlantic and Gulf coasts, the Great Lakes and various rivers. By this time, dredging was generally administered by the Corps of Engineers. The typical type of dredge used in the coastal harbors was the ladder bucket dredge. By 1850, dipper dredges and scrapers had been successfully introduced on various projects. In 1856, a landmark accomplishment in dredging was achieved in Charleston, South Carolina. After defaulting a contract involving an Osgood scoop-type dredge, Captain Cullum had the first suction hopper dredge built. The self-propelled suction dredge, GENERAL MOULTRIE, was the design of Nathaniel Lebby . . . . Major J. C. Sanford described it as . . . a commercial steamboat, converted into a dredge by the addition of centrifugal dredging pumps, with necessary piping, etc., and with bins constructed in the hold.[38]

CREATION OF MARSHLANDS AND UPLAND HABITAT

Vittor (1972) indicated that the construction of a deep water shipping channel in Mobile Bay near Theodore, Alabama, offers a unique opportunity to demonstrate the potential compatibility between industrial development and ecologically sound management of bay and tidelands. The construction of this project will include the creation of two islands, one with a surface area of about 240 acres and

the second with a surface area of about 700 acres. Each of the islands will be constructed using material excavated from the navigation channel and will be located parallel to the shoreline and to each other with the outer island about 7,500 feet offshore of the shoreline. About four million cubic yards of excavated material will be utilized in the construction of the islands which will protect the existing tidal marshlands along the shoreline. The onshore sides of the islands will have indentations in a scalloped form so that the lagoon-like areas formed by the indentations will be attractive for shrimp spawning and aquatic activity. An open water space will exist between the two islands to provide for water circulation and movement to prevent stagnation and excessive shoaling. In describing the objectives of the project Vittor noted:

> First, it provides an innovative means of assessing the potential for productive salt marsh island development; second, it will provide the world dredging community and regulatory agencies with good information on one method of using dredging spoil in an environmentally sound manner; third, it will establish a great deal of basic information on marsh and bay ecosystems.[39]

For many years excavated materials were discharged at the nearest and most convenient location to the dredging site. In recent years the national concern for the protection of the environment has resulted in many areas being unavailable for the disposal of dredged materials. As a result considerable thought has been directed toward the

beneficial usage of these materials. The construction of marshlands on dredged materials placed along the shorelines of estuaries and beach areas provides an economical and environmental solution to the disposal of dredged materials. One of the recent and successful projects of this nature was described by Woodhouse, Seneca and Broome (1974):

> The maintenance of navigation channels is essential to various activities (shipping, fishing, and recreation) taking place within the sounds and estuaries. For this reason, the Corps of Engineers, U. S. Army, maintains over 2,400 Km of such channels within the boundaries of North Carolina alone. Disposal of materials removed during this process is a growing problem and the stabilization and conversion of any part of this spoil to productive use would be highly desirable . . . . We have learned to handle both seeds and plants of Spartina alterniflora, have established stands by both seeding and transplanting, determined some of the requirements for growth of this plant and developed mechanized procedures for the stabilization of dredge spoil as salt marsh.[40]

The use of dredged material to create marshes and wetlands and the environmental importance of this type of activity was discussed by Graves (1976) based on results obtained from the Dredged Material Research Program conducted by the Corps of Engineers:

> We created wetlands by accident with some of our previous disposal methods. Now we are consciously creating wetlands with dredged material . . . . To date, marsh and habitat development are the most promising productive and beneficial alternatives to open-water disposal . . . . There are ten marsh and terrestrial habitat development sites throughout the country in this phase of the program. The most advanced field investigation of full-scale marsh development is located on the James River near Norfolk, Virginia. The 14-acre marsh was developed from 70,000 cubic yards of dredged

> material from the nearby navigation channel. We planned experimental planting of the site but a natural mix of vegetation rapidly established itself. Wildlife moved in just as rapidly . . . . Research into terrestrial habitat development is looking at the building of biologically desirable habitats using dredging material placed above the high tide line. It is possible that dredged material could be used to develop aquatic habitat. Tidal flats and seagrass beds can be established on dredged material if the bottom is elevated so that it is in the photic, but subtidal zone. Biological productivity would be significantly increased at many sites using this concept.[41]

The feasibility of marsh development on dredge material sites was described by Knutson (1976):

> The planting and monitoring of replicate test plots in an unconfined area has affirmed that dredged material is a suitable substrate for the propagation of intertidal vegetation in the San Francisco Bay . . . . The use of direct seeding is the most promising planting method as it requires the least investment in labor, facilities and equipment. . . . Theoretically, 200 to 250 million m^3 of dredged material could be accommodated along the shores of San Francisco Bay if total utilization was made of the marsh development alternative. Study observations to date indicate that within practical limits, an appropriate marsh topography can be established with available equipment and existing dredging technology.[42]

The biological functions of marshes and the viability of utilizing dredged material disposal sites to create marshlands were summarized by Holloway (1976):

> Some of the important biological functions of marshes include general habitat for fur bearers, waterfowl and aquatic species; food chain production; and nesting, spawning and nursery areas for a wide variety of land and aquatic species . . . . Marshes also protect adjacent areas from wave action, erosion and hurricane damage . . . . Some of the marsh areas in the United States have declined significantly. For example, California has lost approximately 67 percent of its marshes through filling, while New York and New Jersey have lost 10 to 25 percent (Sweet 1971). Gagliano et al. (1970)

> estimated that Louisiana has lost up to 16.5 square miles of marshland per year. While these trends have been reduced in recent years, a significant amount of marshes are still lost each year . . . . The creation of marshes on dredged material is a viable and useful technique for habitat development. However, the state-of-the-art has not progressed to the point that all biological conditions are known for marsh creation.[43]

The creation of upland habitat development areas on dredged materials and the benefits derived from these areas were described by Hunt (1976):

> Disposal sites are often islands, physically and/or biologically, which offer a species isolation and freedom from disturbance. Overboard disposal of dredged material in the nation's intracoastal waterways has resulted in emergent land which provides breeding ground for over 30 species of colonial nesting birds. This newly formed habitat has assumed great importance to bird populations since their historic breeding areas have been encroached upon by coastal development. Soote and Parnell (1975) found 19 species of birds to be heavily dependent on dredged material islands (this dependency was defined by the birds placing over 50 percent of their nests on dredged material islands as opposed to other types of nesting areas). In 1973, the same authors found 83 percent of all ground nesters in the estuaries of North Carolina on dredged material islands and 17 percent on natural sites.[44]

In reviewing the factors related to the use of dredged material for habitat development, Smith (1976) found that:

> Habitat development on dredged material offers a promising alternative to the more conventional open-water and upland confined disposal methods . . . . Marsh creation has received the most testing and evaluation, and the factors which dictate the feasibility of a disposal technique are fairly well defined for that alternative. Although habitat reclamation on upland disposal areas has received comparatively little consideration, the state-of-the-art is such that the biological productivity of most upland sites can be improved through standard wildlife management

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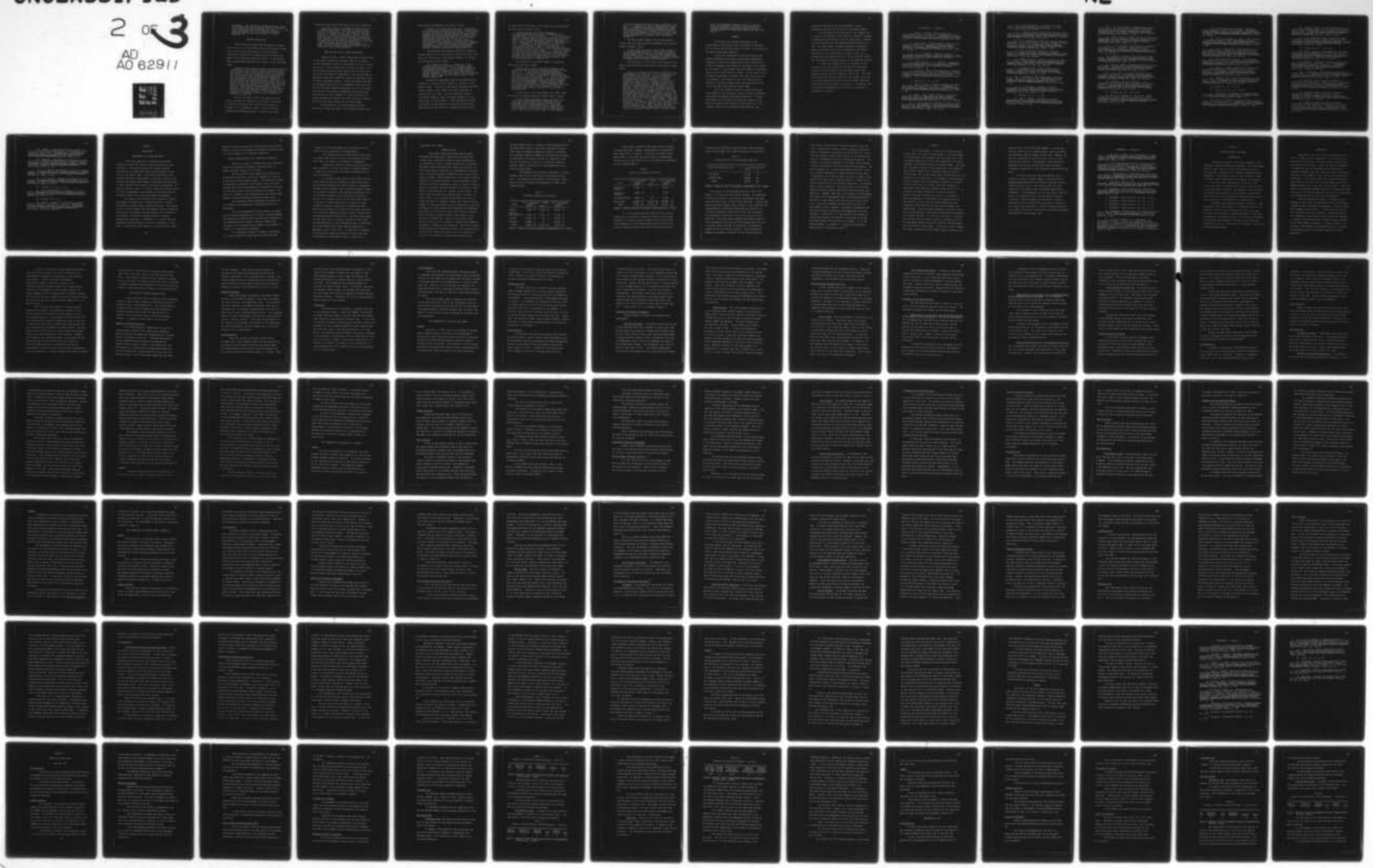

> techniques. The creation of dredged material islands as a disposal alternative may be used for selected areas to provide nesting habitats for birds . . . . The least understood, but still promising, disposal technique involves the establishment of aquatic habitats.[45]

COASTAL ENGINEERING

Watts (1972) indicated that the physical changes which occur at an uncontrolled inlet, with respect to time, are a result of the relationship of sand (littoral materials) available for transport and the transporting agents of tide and wave induced currents. In discussing these changes Watts explained the effects of ebb and flood tides:

> Basically, wave induced currents transport materials along shore to the inlet; on flood tide the materials are carried to the interior part of the inlet complex and deposit on what is frequently called an inner bar; and, on ebb tide, some of the materials deposited in the inner complex are transported back seaward to an area frequently called the ocean bar. During the period of ebb tide, materials transported to the inlet by wave action are also carried to the ocean bar zone. Ebb and flood tide channels form in both the ocean and inner bar formations and these channels generally migrate. Their geometry and migration are related to the rate of littoral material movement to the inlet and prevailing tidal currents. Also involved is the transport of materials along the bar formation by littoral processes.[46]

Sorensen and Mason (1972) indicated that waves usually approach the coastline at an angle to the beach. As they enter shallow water, some of their energy is expended in the movement of sand in the form of both suspended and bedload transport. Littoral drift and

longshore transport were described by Sorensen and Mason:

> Additional energy is consumed in the creation of a current which, due to the angle of attack, moves parallel to the beach. The sand moved by this wave activity is termed littoral drift, and the current produced is called the longshore current. The longshore current and wave action produce a movement of sand along the coast known as the longshore transport. The magnitude of the longshore transport is primarily a function of wave height and breaker angle . . . . In order to evaluate the dredging requirements at an inlet, the total annual longshore transport past the inlet must first be determined.[47]

PORT AND ARTIFICIAL ISLAND DEVELOPMENT

Schmid and Garcia (1974) forecasted an energy crisis in the United States and indicated there was a need to proceed immediately with the improvement of ports to avoid the crisis. They presented the view that the ports in the United States do not have the capabilities to handle the near-term requirements of imported oil and gas and that an ambitious program was needed to create new deep-water ports to receive petroleum imports. Schmid and Garcia indicated the "deepwater ports built to accommodate large ships not only will provide economic advantages but also will reduce the risks of collisions and groundings and provide more protection to the environment."[48] Their forecast of an energy shortage was accurate but their advice to construct facilities for super tankers has not been heeded.

The importance of providing adequate channel dimensions to meet the needs of the shipping industry was

highlighted by Montgomery and Griffis (1974):

> Presently, the Corps maintains over 19,000 miles of waterways and 1,000 harbor projects. The importance of these projects to the economic growth of the USA is evidenced by record breaking advances in water-borne commerce during the 20-year period from 1950 to 1970. An 85 percent increase resulted in a total tonnage transported in 1970 of over 1.5 billion tons . . . . Future projections indicate a continuing important role for water-borne commerce in the nation's economic development. In addition to enhancing water-borne commerce expansion, the maintenance of waterways provides extensive recreational opportunities.[49]

The requirment for dredging to maintain adequate channel dimensions in the shipping routes of the Ems, Jade, Wiser and Elbe Rivers in the Federal Republic of Germany was described by Nagel (1974):

> The increasing traffic of large ships in the different areas also requires an increased output in maintenance dredging. It is no longer enough to concentrate on the removal of large area drift-ins, but the many small area drift-ins in the numerous grooved stretches of the ship channels must be removed several times a year, up to 8 times a year in some channel sections.[50]

Beneath the underwater area of Long Beach Harbor, California, lies one of the largest oil reserves in the United States. The City of Long Beach contracted with the Texaco, Humble, Union, Mobile and Shell Companies to develop this oil field. The five companies formed a corporation known as Thums Long Beach Company to act as their agent for this project. After considering various alternatives it was decided to construct an artificial pennisula and four artificial islands to serve as bases

for the drilling operations. The scope of the construction was described by Russell (1967):

> Construction of the 300 acre pennisula . . . required 30,000,000 cubic yards of dredge fill and 3,000,000 tons of rock for armor . . . . The first island has 8.8 surface acres and the others have 10 acres each. They are in water depths varying from 28 feet to 40 feet. These islands required a total of 3,800,000 cubic yards of dredge fill and 631,000 tons of rock armor . . . . Construction of the fourth island was completed by the end of 1966. In the meantime, oil was being produced on the first island and drilling was in progress at the second island . . . . Hydraulic dredge-filled land has certainly proved to be a good solution to Thums Long Beach Company's problem of providing an adequate and solid base from which to drill and operate the many wells which ultimately should produce over one billion barrels of crude oil.[51]

The planning for port development in Canada was discussed by Williams (1976):

> We have two or three significant projects under study which will have major dredging components. The first is . . . the channel of the MacKenzie River. This is our only major river waterway extending to the Arctic. It is about 1,000 miles long and provides an 8-foot draught at low water . . . . We are continually being required to provide heavy engineering imput to plans for the development of Arctic ports as support for resource development. Although there has been little port construction to date, considerable activity has taken place in our Arctic waters in the form of construction of offshore islands for oil and gas exploration.[52]

In describing a port development plan under study by the Port of Hamburg, Germany, Nauman (1974), stated:

> For the first development stage, six berths for ships with loading capacities of 250,000 tons are envisaged for the harbor basin and the port and industrial area to be developed will cover about 1,250 hectares or 3,088 acres, large enough to take up ore handling facilities as well as large industrial plants such as a steel plant, a big refinery,

> an atomic-energy plant and possibly a chemical plant, too. . . . Dredging of access, roadstead and harbour basin, reclamation of about 1,250 hectares of land and construction of the connection dam to the mainland involve movement of as much as 95 million cubic metres of sand and there is no doubt that this could be accomplished only by modern suction dredging methods.[53]

The relationship between size of the dredging industry and the construction of waterways and ports was cited by Brouwer (1974):

> In particular during the last decade, industry has shown tremendous growth. This is mainly due to a vast demand for deep-sea port harbours, waterways and reclaimed areas. To cope with this demand large amounts of money have been invested in the construction of bigger and more sophisticated dredges.[54]

The benefits to Florida and to the nation of the Tampa Harbor Navigation Channel were discussed by Limoges (1976):

> Tampa is a primary distribution, collection, and trading center for Florida. In its hinterland live approximately 25 percent of Florida'a population. The port of Tampa's marine tonnage in 1975 was 40,945,662 tons, which represents a five-year increase of 26.4 percent. Nationally, the port of Tampa ranks eighth in total tonnage and fourth in exports. Of this amount of foreign exports, phosphate and phosphatic fertilizer accounted for 91.0 percent. It is projected that the deeper channel and turning basins will provide more efficient bulk cargo handling for this valuable export. It is also projected that there will be a reduced shipping cost for petroleum products due to deepened channels. At present, Tampa's petroleum inbound cargo accounts for 54.7 percent of the total inbound tonnage. Therefore, among the benefits . . . are lower utility rates for customers. In addition, general cargo cost could be reduced which will also lower various commodity prices in the tributary area. Other potential benefits realized from the harbor deepening project would be reduced navigational hazards, which, in turn, could

lessen environmental dangers, such as oil spills. Also, the placement of suitable, clean sand could provide increased recreational areas and would provide material for beach nourishment and replenishment.[55]

SUMMARY

In reviewing the related literature it was surprising to find so many early references to the need for utilizing the offshore zone as a source for construction and beach nourishment materials.

It was also surprising to find that many of the papers presented at the seven international conferences sponsored by the World Dredging Association referred to a variety of subjects that relate to the theme of this paper. At the outset, it was thought that the number of references that could be cited would be limited. As the review of the literature continued, it became clear that this would not be a problem. As a matter of fact, the compilation of references from the review of the literature may well be one of the major contributions of the paper.

It was the original intent to locate references that related to the shortage of sand and gravel, equipment requirements and beach-nourishment operations. However, the chapter also includes citations that pertain to the need for improving the degree of professionalism in the dredging industry, early dredge design features, the

creation of marshlands and upland habitat, coastal engineering and port and artificial island development.

As indicated at the beginning of this chapter and in some of the citations, the volume of literature relative to dredging activities was scarce for many years. However, since the inception of the World Dredging Association in 1967, the total number of pages contained in technical papers presented at the seven international conferences sponsored by this organization is 5,547. Thus, it is evident that considerable effort is being directed toward the improvement of professionalism in the dredging industry.

In the next chapter, there is a summary of the increasing need for developing the means of excavating material from the offshore zone for beach nourishment purposes and the factors relating to this need. The scope of the shoreline erosion problem in the United States and the various methods that may be used to combat shoreline erosion are also discussed in Chapter 2. In addition, the rationale for the methodology utilized in the study is described in Chapter 2.

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Chapter 3

METHODOLOGY

REQUIREMENTS FOR SAND AND GRAVEL

Continuing population increases and attendant demands for land, food, water, energy and materials have resulted in increasing pressures for greater resource utilization, including more intensive and broader utilization of the coastal areas. With nearly one-third of the nation's population concentrated in the major coastal cities and more than double that number located near the shorelines, or about seventy-five percent of the nation's population in coastal counties, there is a critical need for sand and gravel for fill and aggregate to meet general construction and for shoreline landfill and beach nourishment requirements.

The coastal zone includes a wide variety of physical and hydraulic features and is characterized by a dynamic interaction of winds, tides, currents and waves. This region of great natural beauty, which encompasses sea and strand and which holds a fascination for many people, has historically included many of the more important sites of industry, commerce and recreation.[1] Therefore, it is likely that the population along the coastal areas will continue at a high level or increase and that there will continue to be a great

demand for sand and gravel to provide for the construction, landfill, and beach nourishment requirements associated with this large segment of the national population.

FACTORS CONTRIBUTING TO THE SHORTAGE OF MATERIALS

There are a series of factors which are contributing to the forecasted shortage of sand and gravel. A summary of these factors is as follows:

The most available and lowest-cost sources have already been exploited, resulting in demands for the use of costlier and more remote sources. The population growth and geographic expansion of the coastal cities and their suburban areas have necessitated the relocation of quarries to sites more distant from the metropolitan regions. This causes an increase in the transportation cost and the abandonment of some of the more productive quarry sites.

The population growth throughout the nation with its attendant requirement for increased quantities of aggregates.

The rising standard of living, which is bringing about increased automotive and air travel, the development and expansion of suburbia with corresponding increases in the requirements for highways, bridges, airports and structures, all of which usually require large amounts of landfill and construction aggregate.

The tremendous increase in outdoor recreational activities, especially those that are water and beach

related, with the requirement for construction of new facilities and restoration of eroded beaches.

The increased need for offshore facilities such as nuclear power plants, airports and offshore unloading facilities, all require vast amounts of aggregates.

Legislation enacted by states and municipalities, often prohibits or limits the mining of onshore deposits in some areas and deposits located on submerged land in bays and estuaries.[2]

As indicated above, many of the onshore sand and gravel deposits that are suitable for beach nourishment or restoration purposes and that are within a reasonable distance from the coastal areas are being depleted rapidly. It is generally agreed by the engineering community that the existing shortage of sand and gravel from onshore quarries will become critical in the next twenty years or so and that a concentrated effort is needed to locate alternate sources of supply and to develop efficient methods and equipment to excavate and transport the materials from the alternate sources of supply.[3] Recycling of already-used sources affords only a very small percentage of total need, and is virtually limited to urban areas. The most attractive of the alternate sources is considered to be the offshore zone since extensive deposits of aggregates exist in this area. In addition, the deposits are distributed along the shoreline in such a way that transportation to the market areas is usually not a

significant cost factor.

SHORELINE DATA

The coastal shorelines of the United States, including the Great Lakes, Puerto Rico and the Virgin Islands have a cumulative length of about 84,300 miles. As indicated in Figure 1, about 20,500 miles of the total shoreline length are undergoing significant erosion; of this amount about 2,700 miles are experiencing a critical rate of erosion and about 17,800 miles have a non-critical rate of erosion. About 63,800 miles of the total shoreline length are in stable condition. The distribution of the shoreline erosion by geographic region is shown in Figure 2. Beaches in general, and sand beaches in particular, erode readily under both wave and littoral current attack. The sand in the surf zone of an exposed beach is seldom in a static state. It is usually moving along, away from or toward the shore in response to waves and littoral forces. Changes in wave and littoral current conditions, along with the removal of dune systems for residential and commercial development, hurricanes and other storm effects, modifications to inlets and other factors cause changes in the shape of the shorelines. Coastal areas serve a great variety of uses such as recreation, seaports and commerce, residential, commercial and aesthetics. The thirty coastal states counting the Great Lakes states, and the territories of the Virgin Islands and Puerto Rico have seventy-five percent of the national population and twelve of the

thirteen largest cities. Changes in the configuration of the shorelines results in the loss of beaches and waterfront lands, substantial damage to highways, residences and structures used for commercial and industrial purposes. In some resort city areas, the loss or reduction in the size of the beach can result in a significant adverse economic impact on tourism in a large geographical area involving many people.

The ownership of the national shoreline is largely private, particularly when Alaska is excluded from the total. The ownership distribution of the national shoreline in terms of mileage and percentage is shown in the following table.

Table 3

Shoreline Ownership Distribution

Owner	U.S., Excluding Alaska Miles	%	Alaska Miles	%	U.S., Including Alaska Miles	%
Federal	3,900	11	41,400	88	45,300	54
States & Municipalities	4,600	12	5,500	11	10,100	12
Private	25,800	70	500	1	26,300	31
Uncertain	2,600	7	-	-	2,600	3
TOTAL	36,900	100	47,400	100	84,300	100

Source. Library, Corps of Engineers, Washington, D. C. (1978)

Only a small portion of the total shoreline length has been developed. However, three-fourths of the undeveloped shoreline is in Alaska. If Alaska is excluded, about three-fifths of the total shoreline length is undeveloped. The major use of the shoreline is for recreation as indicated in the following table.[7]

Table 4

Usage of the National Shoreline

Use	U.S., Excluding Alaska Miles	%	Alaska Miles	%	U.S., Including Alaska Miles	%
Recreation, Public	3,400	9	-	-	3,400	4
Recreation, Private	5,800	16	-	-	5,800	7
Non-Recreational	5,900	16	300	1	6,200	7
Undeveloped	21,800	59	47,100	99	68,900	82
TOTAL	36,900	100	47,400	100	84,300	100

Source. Library, Corps of Engineers, Washington D.C., (1978)

It is surprising that the shorelines with natural beaches are a relatively limited and special resource when related to the total shoreline length of the United States. The information in the following table which excludes the Alaska shoreline indicates that only thirty-three percent

of the national shoreline length includes natural beaches. Alaska was excluded since these data were not available:[8]

Table 5

Characteristics of the National Shoreline

Shoreline Characteristics	U.S. -- Excluding Alaska Miles	%
With Beach	12,200	33
Without Beach	24,700	67
TOTAL	36,900	100

Source. Library, Corps of Engineers, Washington, D.C., (1978)

The erosion of the developed beaches in the United States is a large-scale and serious problem. The magnitude of shoreline erosion is typified by the damages sustained along the south shore of Long Island, New York. Located near major population centers, many sections of this shoreline are representative of advanced development and intensive use. A review of shoreline regression in this area indicates a loss averaging from one-half acre to one acre per mile of shoreline. With land values ranging from about fifteen to sixty thousand dollars per acre, the average land loss due to erosion along 120 miles of shoreline is estimated to exceed one million dollars annually. When coupled with damages to highways, structures and utilities resulting

from storms and wave action along this coastal area, the total average annual damage to shore property and developments is estimated to be about ten million dollars. Aside from the economic losses due to erosion of the shorelines, there is a tremendous loss of a recreational resource. For example, the annual attendance at the major public beaches on Long Island totals more than seventy million people. The most intensive use is at the Jones Beach State Park, which has an annual attendance of about thirteen million, which is equivalent to six million users per mile of beach in this area.[9] It is clear that a concerted effort is justified to control the erosion of the national shorelines. The problem then is how to prevent or limit the extent of the erosion. There are several methods that may be used to achieve this objective. However, they vary in the degree of effectiveness and should not be implemented until a detailed engineering analysis has been made of the conditions existing at the site. The various methods include artificial fill and nourishment, groins, seawalls, revetments, breakwaters and the installation of sand fences and vegetation along the shoreline. Artificial fill, with periodic nourishment to restore and preserve the beaches is considered to be the best method when site conditions will permit. It is the natural method, is aesthetically pleasing and permits a wide variety of recreational uses.[10]

SUMMARY

The survey method, or descriptive study approach, is utilized. The study findings relate to the development of new equipment and procedures and are predicated on the information generated in three test operations utilizing a seagoing, self-propelled hydraulic hopper dredge. Each test was conducted to determine the operational, environmental and economic feasibility of excavating material with a hopper dredge from an open water area and the delivery of the material to an eroded beach. The seagoing, self-propelled hydraulic hopper type of dredge was selected as the basis for the study since it is best suited for operation in open water areas which are subject to wave action.[11] It is intended to present information on the excavation of material from the offshore zone, which is suitable for beach nourishment or restoration, the transportation of the material to sites near the eroded beaches and the discharge of the material from the hopper dredge to the eroded areas. The same hopper dredge was utilized in each test so that the basic operational and production parameters would remain constant. In the first two tests, a floating mooring barge was utilized to serve as a berthing facility for the hopper dredge so that the material could be pumped from the dredge to the beaches. In the third test, a DeLong Pier Barge, elevated above the water surface, served as the

berthing facility for the hopper dredge. It would have been desirable that the digging depths, types of material and discharge pipeline lengths be the same. However, the physical conditions at the three sites varied so that this was not possible. Nevertheless, these operational parameters do not vary to the extent that preclude a reasonable correlation of the information derived from the tests.

In view of the fact that the seagoing, self-propelled, hydraulic hopper dredge is the only type of dredging equipment which can withstand the wind and wave conditions that occur in the offshore zone, any cost comparison with another type of equipment would not be meaningful. The presentation of the test data in the next chapter is intended to show that the design features installed on hopper dredges have resulted in a type of equipment that can successfully, and within a reasonable cost range, provide materials from the offshore zone that are suitable for general construction and beach nourishment requirements in the coastal zone.

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Chapter 4

PRESENTATION OF TEST DATA

INTRODUCTION

Three test operations utilizing a seagoing, self-propelled, hydraulic dredge are described. The same dredge, GOETHALS, was utilized in each test operation to assure that the basic operational and production parameters were comparable. The design features of this dredge are shown in Figure 2 and a photograph of the dredge is at Figure 3.

The first test operation was at Sea Girt, New Jersey; the second at Jacksonville, Florida; and the third at Virginia Beach, Virginia. The purpose of each test was to determine the operational, environmental and economic feasibility of excavating material from the offshore zone and the delivery of the material to eroded beaches.

The tests were conducted because a shortage of sand and gravel from onshore sources is developing rapidly. The materials existing in the offshore zone can be utilized to offset this shortage if suitable equipment is available to operate for extended periods in this hostile environment. The equipment and procedures utilized in the tests were developed by the U. S. Army, Corps of Engineers, to meet this challenging requirement.

BACKGROUND

Dredging is one of the major responsibilities of the U. S. Army, Corps of Engineers. Over the past one-hundred and fifty years, the scope of this responsibility has continued to increase. Today, the Corps of Engineers is responsible for the maintenance of 25,000 miles of navigable channels, 226 locks, dams and other control-type structures, 107 commercial ports and over 400 small ports and harbors. The volume of material excavated annually is about 380 million cubic yards and the annual cost of the dredging operations is over 200 million dollars. About two-thirds of the annual dredging workload is accomplished with contractor plant and the remaining one-third is accomplished with dredges operated by the Corps of Engineers.[1]

Domestic waterborne commerce, including inland waterways, Great Lakes and deep-draft traffic, moves about sixteen percent of the nation's commerce. The total water-borne commerce totals about 1.7 billion tons per year or over 350 billion ton-miles annually. About one-third of this commerce is with foreign countries and the remainder is domestic; with barge traffic comprising about one-half of the total domestic commerce. In most instances it is necessary that dredging be performed annually to provide the flotation depths required for vessels plying the waterways.[2]

In order to perform the annual dredging workload in the most efficient manner, the Corps of Engineers has developed new equipment and techniques to meet changing requirements. Some of the major achievements include development of the first seagoing, self-propelled, hydraulic hopper dredge; the sliding dragarm trunnion, direct pumpout and bow thruster features for hopper dredges; the first dustpan type of hydraulic dredge; the first shallow draft sidecasting type of hydraulic dredge; and the first split-hull type of hopper dredge for use in shallow inlets.[3]

Until recently, the methods of maintaining and improving the depths in the deep-draft channels of the United States did not provide for the beneficial use of the dredged materials. The disposal of materials has been and continues to be mainly in deep water areas at sea, even in the case of sand, which in many cases could be used for the restoration or nourishment of eroded beaches.[4] For many years, the principal source of sand for beach nourishment purposes was from lagoonal and inland deposits. However, during the past ten to fifteen years it has become increasingly difficult to obtain sand from these sources in sufficient quantities and at economical costs due to environmental constraints and to the existing developments along the shorelines. In many instances the material dredged

from estuaries is unsuitable for long-term beach stabilization due to the small grain-size of the sand in these areas. These factors coupled with the increasing shortage of sand and gravel from onshore sources has lead to the need to develop equipment and techniques to utilize the extensive volume of suitable material available in the offshore zone.[5]

EVALUATION OF VARIOUS DREDGING MODES

It was determined that the seagoing, self-propelled, hydraulic type of hopper dredge was the most suitable for extended usage in the offshore zone. The various modes of operation of this type of dredge were then evaluated to determine the mode best suited for the excavation of material from the offshore zone for beach nourishment purposes. A summary of these modes is as follows:[6]

Dumping in Rehandling Basins

This method requires an open-water area which is large and deep enough for the loaded hopper dredge to maneuver into and discharge the dredged materials through gates in the bottom of the hull. The deposited material is then dredged from the bottom of the waterway by a separate piece of plant, usually a cutterhead type, and discharged onto a nearby beach or diked containment area. This technique usually requires the use of two basins or rehandling areas, one for the hopper dredge and the other

for the rehandler. These basins must be located in relatively quiet and protected waters due to the sea-keeping limitations of the cutterhead type of dredge. This type of operation was not selected for the tests because it requires the use of two items of major plant and must be conducted in areas inside estuaries or close to an inlet.

Agitation Dredging

Under this method, the pumps of the hopper dredge continue to discharge the material, even after the hopper has been filled to a pre-determined level. As the pumping operation continues, the material overflows the sides of the hopper and is directed, through chutes, back into the upper level of the surrounding ambient water. The suspended material is then carried away from the shoal area by tidal, river or littoral currents. Since most of the material is not retained in the hopper, this method is not appropriate for obtaining material from an offshore source and transporting it to an eroded beach.

Sump Rehandling

Under this method, the hopper dredge must be equipped with a direct pumpout feature so the material can be removed from the hopper utilizing centrifugal pumps. The loaded hopper dredge proceeds from the dredging site to the place where the rehandling dredge is located. After

the two vessels are coupled together the material in the hopper of the dredge is pumped into the hopper of the sump rehandler which, in turn, pumps the material for extended distances to an eroded beach or a diked containment area. This method was not selected because it involves two items of major plant. In addition, the Corps of Engineers hopper dredges are equipped with machinery and centrifugal pumps which are capable of pumping material extended distances. Therefore, the use of a sump rehandler type of vessel was not required.

Sidecasting

The objective of this method is basically the same as the agitation process. Under this method, the material excavated from the bottom is directed from the centrifugal pumps through a boom-supported discharge pipe. In this case the material re-enters the waterway at the water surface and therefore will be suspended longer and travel farther from the shoal area than in the agitation process. As in the case of the agitation dredging method, the material returned to the waterway is carried away from the shaol area by tidal, river or littoral currents. Since none of the material is retained in a hopper, this method is not appropriate for obtaining material from an offshore source and transporting it to an eroded beach.

Direct Pumpout

As in the sump rehandling mode, the hopper dredge is equipped with machinery and centrifugal pumps so that the material in the hopper can be pumped from the vessel through a discharge pipeline to an eroded beach or a diked containment area. However, in this instance the capability to pump the material for an extended distance, 20,000' without a booster pump, obviates the need for a sump rehandling type of vessel.

The direct pumpout mode of operation was selected for the test operation since it was considered to be the most versatile and efficient of the various available modes to excavate material from the offshore zone, transport the material several miles and then discharge the material onto an eroded beach.

TEST OPERATION AT SEA GIRT, NEW JERSEY

General

Sea Girt is a small resort city located on the New Jersey shoreline about sixty-miles from Philadelphia, Pennsylvania; about thirty-four miles south of the entrance to New York Harbor and about twenty-five miles north of Barnegat Inlet, New Jersey. The shoreline in this area has experienced extensive beach erosion over an extended period. In nearby areas, massive seawalls have been constructed

along the shoreline and through the years the strand has disappeared. At Sea Girt, the erosion has not reached this point. However, the rate of erosion is threatening to destroy structures located along the strand.

Dredge Selection

In 1966, the Corps of Engineers had two seagoing hopper dredges equipped with a direct pumpout capability which were suitable for the test operation; the COMBER and the GOETHALS. The design features of the COMBER are shown in Figure 4. The GOETHALS was selected for the test since its hopper capacity of 6,422 cubic yards was much greater than the 3,524 cubic yard capacity of the COMBER. In addition, the propulsion horsepower and the power available to the centrifugal dredge pumps are about the same. Therefore, the additional hopper capacity would provide a greater efficiency in the loading, transportation and discharge of the material to the beach.[7]

Site Selection

The Sea Girt site was chosen because the shoreline was badly eroded, a typical severe ocean environment would be encountered, and the transportation distance between the offshore borrow area site and the mooring location was short, about 1.5 miles. In addition, the State of New Jersey agreed to the use of a National Guard facility

located along the shoreline. This facility was used as a staging area for the assembly of the submerged pipeline and the pipeline located along the beach, as well as the equipment, materials and supplies required in support of the test operation. Further, the Borough of Sea Girt granted approval to place dredged material on its shoreline and enthusiastically endorsed the operation. The site had one major disadvantage. The nearest inlets which could serve as a refuge for the mooring barge in the event severe storms occurred were New York Harbor, thirty-four miles, and Absecon Inlet, about fifty-five miles away from the test site. A map of the site is included as Figure 5.

Selection of Mooring Arrangement

Several methods of mooring the GOETHALS were considered:[8]

Multiple Sea Buoys. This method envisioned the use of four mooring buoys with a diameter of about eight feet. Each of these buoys would be attached with suitable chain or wire rope to three anchors, each weighing 6,000 pounds. The buoys would be placed to form a rectangular area with a minimum water depth of 30' to accommodate the draft of the loaded hopper dredge. The rectangular area required would be about 300' by 700'. The loaded dredge would arrive within the buoyed area and a tug would then connect

four mooring lines from the dredge to each buoy. The dredge would then be positioned, by adjustments to the mooring lines, such that a connection could be made to a submerged pipeline leading from the buoyed area to the beach. The material would then be unloaded from the hopper of the dredge. After the unloading cycle was completed, the mooring lines would be disconnected and the dredge would return to the borrow area to begin another cycle. This method was not selected because the estimated time to moor, position and disconnect the dredge from the mooring buoys was extensive.

Mooring Barge. The direct pumpout technique used in the Delaware River approach channel to Philadelphia, Pennsylvania, and the approach channel to Norfolk, Virginia, includes the use of a mooring barge to berth the hopper dredges COMBER and GOETHALS. Two mooring barges are utilized; MB-1 and MB-2. These barges have a width of 60' and a length of 250'. In the river operations, dolphins or pilings can be used to fix the mooring barge in a given location so that the connection between the pipeline from the dredge to the barge and then underwater to the submerged pipeline will not move in the horizontal plane. MB-2 was selected for the test because it is equipped with six spuds, each with a diameter of six feet and an "A" frame to handle the pipeline connection between

the mooring barge and the submerged pipeline. Therefore, it was reasoned that the use of this barge might eliminate the need for dolphins or pilings since this was the experience in the Delaware River and Norfolk Harbor.

Mooring Barge Placement and Tests

It was realized that the placement of the mooring barge was a critical factor in the success of the operation because the barge was required to berth the dredge and to confine the movement of the connection between the discharge pipelines. Therefore, it was decided to conduct some tests in the offshore zone prior to the dredging operation to determine the best means of positioning the barge to serve as a berthing facility.

Use of Spuds. The use of spuds in the offshore zone proved to be a failure. Even small waves with heights ranging from two to three feet, would cause the barge to roll or pitch. This caused the spuds to bind in the sleeves or guide wells through the hull of the barge and slowly forced the spuds into the bottom material. If the spuds were not retrieved, they would gradually penetrate to the point that they could not be retracted. In addition, it was observed that the motion of the spuds in their wells was causing flexure of the structural members which would lead to failure of the guide well components. After several tests, the use of this method was abandoned.

Use of Buoys and Anchors. A series of tests were conducted utilizing six anchors, each weighing 6,000 pounds, to moor the barge. It was known that additional anchors would be required to hold the GOETHALS in position against the barge. However, the tests results indicated that this procedure should be successful. Based on the test operation, a system was designed as indicated in Figure 6, consisting of ten anchors.

Alignment of the Mooring Barge

The positioning of the barge to serve as a mooring facility for the hopper dredge was given much thought. The positions considered and tested are discussed below:

Barge Parallel to the Beach and the GOETHALS Moored on the Seaward Side of the Barge. The primary advantage of this arrangement was that during the berthing operation the GOETHALS was able to stem the littoral current running parallel to the shoreline, which assisted the mate in landing the dredge against the barge. During the initial tests a tug was used. However, the use of the tug was discontinued after a few dockings as the mates gained confidence.

A significant advantage of this arrangement was the protection of the barge from wave action by the GOETHALS, which reduced the relative movement between the barge and the GOETHALS during the unloading cycle.

A weakness of this arrangement was that the barge was subjected to the broadside action of waves when the GOETHALS was at the dredging site. A further disadvantage was that the anchor lines leading from the seaward side of the barge were very long and at a gentle angle to assure that the propeller of the ship did not get entangled in the lines.

<u>Barge Parallel to the Beach and the GOETHALS Moored on the Shoreward Side of the Barge</u>. This arrangement required that the mooring barge be located farther away from the shoreline to provide an adequate flotation depth for the draft of the loaded dredge.

The advantage of this system was that the anchor lines leading offshore, which are those most effective against wave and wind action, could be located to provide the most effective lead angles.

The major disadvantage of this arrangement was that the mooring barge was not sheltered by the GOETHALS during the unloading cycle. This lead to an increase in the relative motion between the two vessels and decreased the efficiency of the unloading operation.

<u>Barge with Bow Pointed in a Northeasterly Direction.</u> This arrangement was tested since the most severe wind and wave action were expected to be generated from the north-east quadrant. However, this operation was discontinued

after a short period since it was found that the rolling and pitching actions of the barge were greatest while in this alignment. This was attributed to the great difference in the lengths of the vessels which caused them to roll and pitch at different times and angles.

Wave and Current Conditions. Sea conditions will usually result in more lost time than any other factor while dredging in the offshore zone. Therefore, a wave recorder was placed on MB-2. The recorder indicated that wave conditions ranging from calm to a height of 6' could be expected about 70 to 80 percent of the time, but that occasional wave action in the range of 6' to 12' could be expected.

During the preparation phase, the trial landings of the GOETHALS against the barge indicated that the littoral current ranged from one to one and a half miles per hour, which did not pose an operational problem. Therefore, a current meter was not installed on the mooring barge.

Flexible Connection Design

It was known that the mooring arrangement would necessarily result in some vertical movement due to the pitch and roll of the vessel and some movement in the horizontal plane since multiple lines and buoys were to be utilized. Therefore, a flexible connection was designed based on computations that indicated the barge would move

in an elliptical pattern as the wind and wave action varied. The flexible connection design was based on a barge movement on a 17' radius in a direction parallel to the shoreline or a total movement pattern of 34', and a 45' radius in the onshore--offshore directions or a total movement pattern of 90'.

It was also known that the flexible connection was a vital link in the discharge system. Therefore, the design was predicated on providing both flexibility and strength. The use of reinforced rubber hose was investigated to provide the flexibility required. However, it was found that rubber hose was not available in the 28-inch diameter size required and if fabricated to withstand the estimated internal pressure would not provide the needed flexibility. Therefore, a unit was constructed of steel pipe and ball-joints. Buoyancy tanks were added to the unit so that the entire unit could be removed from the ocean floor utilizing a line pull of only nine tons.

Targets or ranges were installed so that through the use of sextants the location of the barge within the design elliptical pattern could be checked.[9]

Discharge Line

In order to assure that a minimum water depth of 30' was available, it was decided to position the mooring barge 2,000' from the shoreline. Therefore, a submerged line would have to be installed from the barge to the

shoreline. In addition, a pipeline length of 2,000' along the shoreline north of the submerged pipeline and a pipeline length of 1,800' along the shoreline south of the submerged pipeline junction with the beach were required to distribute the dredged material over the eroded section of the beach. Thus, the total length of the discharge line would be 4,000' when pumping to the north and 3,800' when pumping to the south. Both of these distances were well within the pumping capability of the GOETHALS.

Plan of Action

After reviewing the site conditions and the information developed during the preparation phase it was decided to utilize a plan in which the barge would be positioned parallel to and 2,000' from the shoreline. The plan also envisioned the GOETHALS berthing on the seaward side of the barge as indicated in Figure 7.

Test Operations

Positioning of MB-2. Immediately after the arrival of the mooring barge at the site, a storm generated waves with heights ranging from 8' to 10'. During this storm there was some damage to the flexible connection and one of the anchor wires was broken. Repairs were performed and the barge placed in position on March 27, 1966.

Dredging and Unloading Operations. The GOETHALS arrived at the site during the morning of March 28. Prior

to beginning the unloading operations, the GOETHALS landed against the mooring barge to test the mooring anchor arrangement. In addition, water was pumped through the discharge line to assure that it was in functional condition. During the remainder of the day three loads of material were excavated from the borrow area located about 1.5 miles offshore of the mooring barge and 11,899 cubic yards of material were placed on the beach.

Two loads of material totaling 6,635 cubic yards were delivered to the beach during the morning of the next day, March 29. The GOETHALS then departed for New York Harbor, a distance of 34 miles, for a scheduled weekly lay-day during which fuel, water and supplies were obtained and periodic maintenance performed.

During March 30 to May 10 a series of operational problems occurred. These problems included two failures in the pipe sections on MB-2, failure of the restrictor rings on the ball-joints of the flexible connection on three occasions and the failure of an elbow section in the flexible connection. These problems were corrected at the site without any undue difficulties. However, during the hours between midnight and five o'clock on April 13, a sudden storm developed. At the time there were only three crew members on the barge. These men were unaware that the emergency procedures required that some of the anchor wires be released during severe storms. Therefore, the barge

remained parallel to the beach and broadside to the storm winds and waves. About noon on April 13, the mooring barge broke loose from the anchor wires and was swept ashore. Bulldozers were utilized to hold the barge against the shoreline and away from a nearby rock groin until the storm abated on April 14. During the period of April 14 to May 9 repairs were made to the hull of MB-2, an improved anchoring system was installed and the flexible connection repaired and placed in position again. During the period of March 30 to May 10 only twenty-one hopper loads totalling 103,573 cubic yards of material were delivered to the beach due to the series of operational problems.

The GOETHALS, which had been operating in a navigation channel during the period of April 10 through the morning of May 10, returned to the Sea Girt site just before midnight on May 10. From May 10 to May 20, twenty-six hopper loads totalling 127,981 cubic yards of material were delivered to the beach. During this period heavy seas and fog resulted in a lost time factor of about twenty-nine percent. Equipment problems did not occur during this period, although there were indications that further difficulties were developing in the flexible connection.[10]

Summary

A summary of the effective time, production and non-effective time elements during the course of the

March 28 through May 20 dredging and unloading operations is shown in Table 6. The effective time amounted to fifty-four percent of the total time which was much less than the seventy percent which had been estimated. This was due to three factors, the equipment failures, the barge being blown from its mooring and the storm and fog conditions which prevailed during the latter portion of the operational period. The summary indicates a low level of production during the equipment failures ranging from 3,378 to 14,814 cubic yards per day. A production rate ranging from 18,333 to 31,208 cubic yards per day occurred during the latter portion of the period. From an overall viewpoint, fifty-two hopper loads amounting to a total of 250,093 cubic yards were delivered to the beach.

The estimated cost of the project was $700,000 and the actual cost was $680,170 as indicated in Table 7. This resulted in a relatively high unit cost per cubic yard of $2.72, as compared with the estimated unit cost of $2.00. The higher unit cost was due to the low production rate which resulted from the equipment failures and other operational problems. Nevertheless, the actual cost per cubic yard was less than the cost of material which would have been obtained from onshore sites and hauled by trucks to the beach.

The test results indicated that the docking and unloading operations could continue as long as the waves

were less than six feet in height. As the wave heights exceeded six feet, difficulties were encountered and operations had to be discontinued when the waves approached a height of seven feet.

The test indicated that the design of the flexible connection was inadequate and that a significant portion of the non-effective time was due to this design deficiency.

In spite of the equipment and operations problems, it was felt that the Sea Girt operation was a qualified success and that the information developed during the test would lead to more successful tests in the future. Unfortunately, a requirement to assign all of the hopper dredges to navigation channels for an extended period developed which caused an extended delay in plans for future tests.

TEST OPERATION AT JACKSONVILLE, FLORIDA

General

The city of Jacksonville is located in the northeastern section of Florida, about twenty miles south of the boundary between Florida and Georgia. The eastern boundary of the city abuts the shoreline of the Atlantic Ocean and the St. Johns River estuary. The authorized Federal navigation channel leading from the Atlantic Ocean to Jacksonville Harbor includes an entrance or bar channel

with a width of 800' and a depth of 42'. As indicated in Figure 8 there is also an entrance channel located in the lower portion of the estuary of the St. Johns River which leads from the navigation channel to the Mayport Naval Base. This channel has a width of 400' and a depth of 45'.

Dredge Selection

Production estimates made prior to the Sea Girt test operation indicated that the GOETHALS would be the most efficient hopper dredge to excavate material from the offshore zone and deliver it through a pipeline to an eroded beach. The actual production of the GOETHALS during the 1966 test at Sea Girt confirmed the production estimates. Therefore, this dredge was selected for the test operation.

Site Selection

A site in the estuary portion of the St. Johns River was chosen because the shoreline south of the inlet has experienced extensive erosion over an extended period and was badly eroded at the time the test could be scheduled.

The outer or entrance section of the navigation channel leading to Jacksonville Harbor is maintained using hopper dredges since this section of the waterway is subjected to wind and wave action. Dredging is performed every three years or so and about 500,000 cubic yards are removed during each dredging cycle. After determining that the material in the navigation channel was suitable for

beach nourishment, it was decided that a test operation should be coordinated with a scheduled maintenance dredging operation.

The site in the estuary of the St. Johns River offered several advantages as follows:

The shoreline of the Kathryn Abbey Hanna State Park, which has a high public use rate, was eroded badly and in need of nourishment. State officials were consulted and agreed to the use of the State Park shoreline for the test operation.

The site is protected somewhat by the entrance channel jetties. Therefore, the effects of storm winds and waves would be less than at an offshore location.

The average one-way haul distance from the borrow area, about 1.2 miles, would be about the same as the haul distance from an offshore borrow area located in the Atlantic Ocean.

The wave action along the Florida and South Atlantic shorelines is less severe than that occurring along the Northeastern shoreline, which would lessen the docking and unloading problems.

A dual benefit would be realized, that is, the material removed from the entrance channel would improve navigation conditions. In addition, this material would provide a beach nourishment benefit.

The site posed some problems as follows:

Currents in the area occur in stratified layers which would complicate the maneuvering required in the docking and undocking operations.

The distance required to transport one of the mooring barges, owned by the Philadelphia District of the Corps of Engineers, to and from the test site would require a sea journey of 1,750 statute miles and a significant expenditure.

The maritime traffic utilizing the navigation channel would result in more non-effective time than an offshore operation.

After considering the advantages and disadvantages the site in the estuary of the St. Johns River was selected for the test operation.

Selection of Mooring Arrangement

Based on the information developed during the Sea Girt test it was decided that a mooring barge would be used in lieu of an anchoring system for berthing the dredge.

Mooring Barge Placement and Tests [11]

As in the case of Sea Girt, the placement of the mooring barge was considered to be an important factor in the success of the operation. Several sites located at about the mid-point of the southern shoreline of the

entrance channel leading to the Mayport Naval Base were considered since these sites would be entirely protected from storm winds and waves. However, these sites had several disadvantages as follows:

Extensive maneuvering of the GOETHALS would be required in this narrow channel with a width of 400'. The only two options available, since the channel width is less than the length of the GOETHALS, were to back out into the navigation channel when leaving the mooring barge or proceed to the Naval Base basin, turn around and return to the borrow area in the navigation channel. The first option involved a safety risk and the second involved a signficant increase in the operational cycle.

The discharge pipeline leading to the Kathryn Abbey Hanna State Park would have to be laid through the grounds of the Naval Base. Because of security precautions, this would involve some delay problems for Corps of Engineers personnel engaged in the repair and maintenance of the pipeline.

The mooring barge with the GOETHALS berthed alongside would encroach upon the narrow entrance channel leading to the Naval Base. This would pose a maneuvering problem for the large Navy ships using the channel and possibly a safety risk.

Therefore, it was decided to place the mooring barge as close as possible to the south jetty at the point where

the jetty alignment curves and follows the shoreline along the channel leading to the Naval Base as shown in Figure 9.

Use of Spuds. The mooring barge was positioned so that one end of the barge was within 30' of the jetty slope. This simplified the trestle arrangement for the discharge pipeline leading to the shore. The water depth on the off-shore side of the barge ranged from 37' to 40'. Based on the length of the spuds on the mooring barge there was some doubt that these spuds could be placed firmly enough into the bottom material to assure that the barge would not move during the docking and undocking operations of the GOETHALS. On the inshore side of the barge the water depths ranged from 15' to 25', which did not pose a problem from a spud penetration viewpoint. Since the site was reasonably protected from wind and wave action it was decided that spuds would be utilized on both the offshore and inshore sides of the mooring barge.

Use of Buoys and Anchors. As indicated in the preceding paragraph a decision was made to use spuds to hold the mooring barge in position. However, since there was some concern over the penetration depth into the bottom material of the spuds on the offshore side of the mooring, it was decided to reinforce these spuds with two wire ropes leading to two 2½ ton anchors placed near the jetty slope on the shoreward side of the mooring barge.

Alignment of the Mooring Barge

The alignment of the mooring barge along the curve in the south jetty was based on an anlysis of the bottom materials in this area. The analysis was made to determine those points at which the spuds on the barge would penetrate to an optimum depth into the bottom material and thus secure the barge in a given position.

Even though the mooring barge position was in a protected location, the heights of waves generated through the entrance channel jetties were recorded for a thirty-day period prior to the test operation. Based on these observations, it appeared that the waves in this area would range from 1' to 4' which should not cause any serious operational problems during the test.

In addition, current directions and velocities in the location of the barge site were recorded. This information indicated that currents up to 5 knots could be expected during the peak periods of the flood and ebb tides. The data indicated that the currents tended to stratify during the tidal change periods and on occasions these stratified currents would flow in different directions. The peak current velocity and the flow patterns of the currents were matters of concern. Nevertheless, it was felt that the experienced officers of the GOETHALS would be able to conduct the docking and undocking operation successfully.

Flexible Connection Design

A trestle section was constructed leading from the mooring barge to the jetty and to the shoreline. The discharge pipeline from the mooring barge was then placed on the trestle. Since the barge was to remain in a fixed position, an elaborate flexible connection was not required. In addition, the proximity of the mooring barge to the south jetty eliminated the need for a submerged pipeline. Ball-joints were installed at the pipeline connection on the barge to provide for the vertical movement of the barge due to the mean tidal range of 4.5' to 4.9' and the surge action due to the heights of the waves in the inlet.

Even though the mooring barge was to be positioned using spuds reinforced by two anchors, targets or ranges were installed so that any change in the position of the barge could be checked through the use of surveying instruments.

Discharge Line

The shoreline immediately to the south of the south jetty was in stable condition and did not need any nourishment. The eroded section of the shoreline in the Kathryn Abbey Hanna State Park area began at a point about 3,000' south of the jetty and extended to a point that was about 8,200' south of the jetty. Thus, while a submerged pipeline of 2,000' was not needed as in the case of the Sea Girt

test, a longer pipeline of 3,000' was needed along the shoreline to reach the eroded section of beach. In addition, the total length of the discharge pipeline, 8,200', was greater than the maximum pumping distance of 4,000' at Sea Girt.

From an installation and repair viewpoint, a submerged pipeline is significantly more costly and difficult to maintain than a pipeline installed along a shoreline.

Plan of Action

After reviewing the site conditions and the information developed during the planning and preparation phase, it was decided to utilize a plan in which the mooring barge would be positioned along the curve in the south jetty alignment as described above. In addition, it was decided to proceed with the details of the plan developed during the planning phase.

Test Operations

Positioning of MB-1. Mooring Barge-1 (MB-1) was not moved from the test site at the curve in the south jetty alignment. This permitted an orderly installation of the discharge pipeline along the shoreline prior to the arrival of the GOETHALS at the site. MB-1 was selected for use since there was not a need for an "A" frame to handle a submerged flexible connection as was the case at Sea Girt.

The design characteristics of MB-1, which are essentially the same as the MB-2, are shown in Figure 10.

<u>Dredging and Unloading Operations</u>

With the mooring barge in position and the discharge line in place, the GOETHALS commenced dredging in the navigation-channel at 5:26 P.M. on March 25, 1974.

The docking, unloading and undocking of the GOETHALS proceeded without any difficulties and the efficiency of these operations improved after the first several days of operation. Unusual turbulence and 30-knot winds occurred during some of the docking operations but the docking-undocking operations proceeded without damage or lost time. The berthing arrangement of the GOETHALS and the MB-1 is shown in Figure 11.

As opposed to the extensive equipment and operational problems experienced during the Sea Girt test, the lost or non-effective time due to these problems during this operation were minimal. However, in spite of the precautions taken, the mooring barge drifted from its position toward the channel on April 1 and broke the pipeline connection between the barge and the jetty. MB-1 was repositioned and the pipeline repaired during a three-hour period. This was the only equipment problem experienced during the entire test period.

The weather conditions were favorable through most of the test period. The only non-effective time experienced

as a result of weather conditions were sixteen hours during March 26-28 which were due to dense fog.

An unexpected operational problem occurred due to the type of material excavated from the navigation channel. Samples taken from the bottom of the waterway prior to the test indicated that the material was a medium grain-size with some shell in the mixture. As the dredging operations got underway it was soon apparent that the material contained a large percentage of oyster shells in some areas. As a result, plugs in the pipeline during the period of April 1-6 resulted in a total non-effective period of 21.5 hours. During the latter portion of the test this type of difficulty did not occur. However, seventeen hopper loads containing a large quantity of oyster shells were hauled to and dumped in an open water disposal area in the Atlantic Ocean rather than risk additional plugging of the discharge pipeline. In the overall, 53,263 cubic yards of material were disposed of in this manner.[12]

During the test period of March 25 to May 1, one hundred twenty-five hopper loads of material totalling 400,170 cubic yards were delivered to the beach of the State Park through a pipeline with a 28-inch diameter. The total length of the discharge pipeline at the beginning of the work was 3,000' and the maximum length of the discharge pipeline was 8,200'.

Summary

A summary of the effective time, production and non-effective elements during the course of the March 25 to May 1 test operation is shown in Table 8. The effective time amounted to 83.2 percent which was considerably better than the 54 percent achieved during the Sea Girt test. The improvement in the effective time percentage was undoubtedly due to the protected site of the mooring barge, the use of a pipeline located on the shoreline rather than a submerged pipeline and the experience gained during the Sea Girt test.

The estimated cost of the project was $894,500 and the actual cost was $919,160 as indicated in Table 9. This resulted in an actual unit cost per cubic yard of $2.30 as compared with the estimated cost per cubic yard of $2.24. The actual cost per cubic yard of dredging the navigation channel and disposing of the material at sea during the test was $0.80 per cubic yard. Therefore, the cost attributable to the beach nourishment phase of the project using material that would normally have been wasted at sea was $1.50 per cubic yard. In addition, the total cost per cubic yard was less than the cost of material which could have been obtained from onshore sites and hauled by trucks to the beach.

The project was considered a success by the Corps of Engineers, Florida state officials and the public. A headline in the May 1, 1974 edition of the Florida Times-Union,

Jacksonville, Florida, read "Hanna Beach Restoration Work is Hailed as Major Success." The width of the beach which averaged less than 100' at high tide was 400' wide at the end of the test. The improvement in the width of the strand is shown in Figure 12.

TEST OPERATION AT VIRGINIA BEACH, VIRGINIA

General

Virginia Beach is the primary public beach fronting the Atlantic Ocean in the State of Virginia. Adjacent to the cities of Norfolk and Chesapeake, the boundaries of Virginia Beach extend from Cape Henry at the mouth of the Chesapeake Bay to the boundary between North Carolina and Virginia.

Over a period of more than twenty-five years storms and erosion of the shorelines have resulted in extensive structural and economic losses. Because of these losses, the City of Virginia Beach has carried out an annual nourishment program for many years using small hydraulic cutterhead dredges to pump about 150,000 cubic yards of material from nearby estuaries to the beach each year.

Dredge Selection

The production rates of the seagoing, self-propelled, hydraulic hopper dredge GOETHALS during the Sea Girt, New Jersey and Jacksonville, Florida tests confirmed that

the GOETHALS was the most efficient hopper dredge available to the Corps of Engineers to excavate material from the offshore zone and deliver it to an eroded beach. Therefore, this dredge was selected for the test operation.

Site Selection

The Virginia Beach site was chosen because the entire shoreline of the city was badly eroded. In addition, the sources of material in the nearby estuaries were not available due to an unexpected series of developments relating to environmental matters. Because of this sudden development which occurred during the spring of 1974 and a particularly high rate of erosion during the previous year, the officials of the city indicated there was an urgent need for the Corps of Engineers to provide assistance. The city officials were aware of the Sea Girt and Jacksonville tests and requested that a similar operation be arranged as soon as possible at Virginia Beach.

As indicated in Figure 13, the offshore end of the Thimble Shoal navigation channel leading to Norfolk Harbor is opposite Cape Henry which is near the northern boundary of Virginia Beach. The Corps of Engineers is responsible for the maintenance of this channel, which extends eleven miles from the mouth of Chesapeake Bay to the entrance of Norfolk Harbor. This channel has two authorized sections; one with an authorized width of 1,000' and a depth of 45'

and two auxiliary channels adjoining each side of the main ship channel. Each of the auxiliary channels have an authorized width of 450' and a depth of 32'. Samples of material taken from the bottom of the channel were analyzed and, as was the case in the two prior test operations, found to be unpolluted based on criteria established by the Environmental Protection Agency. The material excavated from the Thimble Shoal channel is normally disposed of in the Atlantic Ocean which involves an average one-way haul distance of 22.4 miles.

Based on the urgent need for beach nourishment expressed by the city officials and the potential dual benefit of an improvement to navigation and the utilization of the excavated material for beach nourishment, the Virginia Beach site was chosen for the test operation.

Another factor leading to the selection of the Virginia Beach site was the desire to conduct another test in an exposed location to determine whether the results would be better than those experienced at Sea Girt.

Selection of Mooring Arrangement

Based on the information developed during the Sea Girt and Jacksonville tests it was decided that a barge should be used in lieu of an anchor and buoy type of arrangement. It was known that the Corps of Engineers mooring barges, MB-1 and MB-2, could not be positioned in the

offshore zone using spuds for the reasons stated in the description of the Sea Girt test. Therefore, it was decided to arrange for the loan of a DeLong Pier Barge from a military source.

The DeLong Pier Barge considered suitable for the test has a width of 80' and a length of 300'. The barge is equipped with ten spuds or caissons, each with a diameter of 6'. The barge can be floated into a given position and the spuds dropped to the bottom of the waterway. The barge is then elevated above the water surface by cylindrical jacks located around each of the spuds on the deck of the barge. This type of barge, which was used in the Republic of Vietnam to provide berthing facilities for supply ships, is shown in Figure 14.

After confirming that a DeLong Pier Barge was available on a loan basis from Fort Eustis, which is located on the James River near Newport News, Virginia, it was decided that this type of barge would be used as a part of the offshore mooring facility.

Mooring Barge Placement and Tests[13]

As in the case of the two previous test operations, the placement of the mooring barge was considered to be an important factor in the success of the operation.

A site located directly offshore and about midway of the length of the Virginia Beach shoreline was considered

initially. Due to the gradient of the offshore slope in this area the closest point to the shoreline that would accommodate the loaded draft, 30', of the GOTHALS was about 10,000'. The test at Jacksonville, Florida, indicated that the pumping efficiency of the GOETHALS diminished rapidly when the total length of the discharge pipeline exceeded 8,000'. Therefore, it was necessary to investigate the feasibility of placing the mooring barge in another offshore location.

Based on an analysis of hydrographic data, a site offshore of Cape Henry was evaluated. The evaluation indicated that the DeLong Pier Barge could be located about 1,000' to 1,500' offshore and 2,000' to 3,000' to the east of the Cape Henry shoreline. After careful consideration of all of the various offshore locations the Cape Henry site was selected for the placement of the DeLong Pier Barge.

Use of Spuds. The use of spuds is required to elevate a DeLong Pier Barge above the water surface. The spuds on the DeLong Pier Barge borrowed from Fort Eustis had a total length of 78'. Based on an analysis of material taken from the selected offshore site it was estimated that the spuds would not penetrate more than 20' to 30' into the bottom material. This was a critical factor since at least 15' of spud length must be reserved to stay within the pneumatic jacking frames located on the deck of the barge.

It was estimated that the length of the spuds would be suitable; 30' of maximum penetration, the barge elevation of 5' above the mean low water elevation, 17' through the guidewells of the hull, and 15' in the jacking frames above the deck level of the barge totalled 67'. Thus, the estimate indicated there should be a small reserve spud length of about 11'.

The use of spuds to elevate the barge above the water surface would assure that the barge remained in a fixed position during the docking, unloading and undocking operations. This was considered an essential factor since the movement of the barge on the anchoring and buoying arrangement at Sea Girt had lead to extensive mechanical problems in the submerged flexible connection unit.

Use of Buoys and Anchors. As indicated in the preceding paragraph, a decision was made to use spuds to hold the DeLong Pier Barge in position. Therefore, the supplemental use of buoys and anchors was not considered to be necessary.

Alignment of the DeLong Pier Barge[14]

Alignment. The alignment of the DeLong Pier Barge was predicated on two factors. The first was the type of material in the various offshore locations along the shoreline. A review of this information was necessary to assure

that the total length of the spuds would be adequate. The second factor involved was a determination that the water depths in the vicinity of the barge were adequate for maneuvering the GOETHALS during the docking and undocking operations. Based on these factors an area was selected about 1,000' to 1,500' offshore and 2,000' to 3,000' east of the Cape Henry shoreline. The alignment of the barge was generally parallel to the shoreline.

It was also decided that the GOETHALS would berth along the seaward side of the barge. Consideration was given to docking the GOETHALS on the shoreward side of the barge so that the elevated barge, acting as a breakwater, would reduce the wave action against the GOETHALS. It was felt that this would provide a significant increase in the effective time of the operation. Therefore, this matter was debated at some length. In spite of the estimated advantage of this arrangement it was not utilized because the shape and size of the area in which adequate depths were available were such that there might be some difficulty in manuevering the GOETHALS into and out of the area.

<u>Wave and Current Conditions</u>. A review of the records maintained by the National Weather Service at the Norfolk Regional Airport located about three miles inland from the site indicated that winds could be expected in the range of 5 to 30 miles per hour. The review also indicated that the

winds from the northwest and northeast quadrants would probably generate the largest waves.

The test was scheduled to begin early in October, 1974. A review of wave data obtained from a wave gage located on the southern-most portal island of the Chesapeake Bay Bridge-Tunnel indicated that wave heights ranging from calm to 8' could be expected. However, the review also indicated that waves ranging from 6' to 8' should occur less than twenty percent of the fifty day test period. Tidal currents in the area range from 2 to 2.5 miles per hour and flow generally parallel to the shoreline. Currents of this magnitude were not expected to have a serious adverse effect on the test operations.

Environmental Considerations. The lower portion of Chesapeake Bay is a major spawning and development area for oysters, clams, blue crabs and a wide variety of fish species. Environmental interests felt that the dredging activities, coincident with the critical stages of the life cycles of the marine organisms, might be ecologically damaging. After considering the various environmental factors and the urgent need for beach-nourishment, the project was rescheduled from the summer to the fall of 1974.

Use of the MB-2. The DeLong Pier Barge borrowed from Fort Eustis did not have an "A" frame, saddles for the installation of the discharge pipeline or winches for

attaching and adjusting the spring lines needed to berth the GOETHALS against the barge. The installation of the equipment for the test and removal prior to returning the barge to Fort Eustis would have been expensive and wasteful. Therefore, it was decided to place Mooring Barge-2 (MB-2) on the offshore side of the DeLong Pier Barge to avoid any modification to the borrowed barge. MB-2 was selected since the auxiliary "A" frame on this barge would be needed to handle the submerged flexible connection.

A fender system was required to absorb the impact of the floating MB-2 against the fixed DeLong Pier Barge. The system consisted of two piling units installed about 155' apart and adjacent to the offshore side of the DeLong Pier Barge. Each unit included a row of ten timber piles driven vertically about 15' into the bottom material and extending above the deck level of the DeLong Pier Barge. The piles in each unit were laced together with wire rope and secured to the side of the DeLong Pier Barge hull. An assembly of four horizontal rows of 15-inch diameter cylindrical rubber fenders, connected by metal chain links, was hung from the deck of the DeLong Pier Barge to serve as a flexible spacer and to provide a wearing surface between the pier barge and the timber piles. The remaining components of each of the fender units were two foam-filled fenders, shackled together in a series configuration. These

fenders were placed so that they would float alongside the piling units and cushion the impact of MB-2 against the DeLong Pier Barge. These cylindrical fenders were 4' in diameter and 7.4' in length and were comprised of flexible, closed-cell, cross-lined polyethylene foam with a density of about 2 pounds per cubic foot. The fenders were designed to provide an energy absorption capability of 26 foot-kips and a reaction force of 40 kips, both at 50 percent deflection.

Flexible Connection Design

A floating line from the MB-2 to the shoreline was considered because of the many problems with the submerged flexible connection during the Sea Girt test. Flotation of the steel pipeline would be accomplished by attaching buoyancy jackets of molded polyurethane to each pipe section. A series of anchors would be placed on both sides of the floating pipeline to restrain the line from wave action surges. However, the polyurethane jackets could not be delivered prior to the beginning of the test. Therefore, it was necessary to utilize a submerged flexible connection.

Following the completion of the Sea Girt test, the submerged flexible connection used on this project was modified and strengthened. It was decided that this unit, which was in storage at a Corps of Engineers facility near

Philadelphia, would be utilized. This decision was made with some confidence since the mooring barge was to be secured in a relatively fixed position by attaching it to the DeLong Pier Barge.

Discharge Line

In order to assure that a minimum depth of 30' was available, it was estimated that the DeLong Pier Barge and the MB-2 would have to be positioned about 1,000' to 1,500' offshore and about 2,000' to 3,000' east of the Cape Henry shoreline. Based on these figures it was estimated that the total length of the discharge pipeline would range from 3,500' to 5,000'.

The coupling between the offshore extremity of the submerged pipeline and the flexible connection was designed so that the flexible connection could be lowered to the bottom of the bay and buoyed in the event a hurricane or any severe type of storm should develop during the test period that would necessitate moving the MB-2 to a protected area.

Emergency Plan

The final phase of the planning effort was the formulation of proecedures that should be undertaken in the event of an emergency situation due to rough seas and storms. The plan included a procedure for continuous

monitoring of weather conditions and forecasts on the GOETHALS and at a base station at a local Corps of Engineers facility. The plan also indicated that when wave heights approached 6', which had been the point at which difficulties were encountered during the Sea Girt test, a task force including the captain of the GOETHALS, the officer in charge of the DeLong Pier Barge and designated engineers of the Corps at the base station would decide whether dispersal of the equipment and personnel was necessary. If a decision was made that dispersal was necessary, the GOETHALS would leave the mooring barge berth and either ride out the storm at sea or proceed to a sheltered anchorage. The officer in charge of the DeLong Pier Barge would make the determination as to whether the barge should be elevated and stay in position or be lowered to a floating position and moved by a tug to sheltered waters inside an estuary. The designated engineers of the Corps would make the determination whether the MB-2 would remain berthed to the DeLong Pier Barge or proceed to a sheltered area. In the case of the DeLong Pier Barge and the MB-2 the nearest inlet which could be used as a harbor of refuge was Little Creek inlet, located about 1.5 miles from the test site. The details of the plan were to be included in a document which would be distributed to all personnel engaged in the operation.

Plan of Action

After reviewing the site conditions, the results of the Sea Girt and Jacksonville tests, and the equipment and operational requirements at the site, it was decided to utilize the hopper dredge GOETHALS to perform the dredging work. It was also decided that the berthing facility would consist of a DeLong Pier Barge and the MB-2 to preclude modification of the DeLong Pier Barge borrowed from Fort Eustis. Based on the maneuvering requirements of the GOETHALS, the plan provided for the GOETHALS to dock and undock on the seaward side of the MB-2.

The total length of the discharge pipeline required to pump the materials to the Cape Henry beach was estimated to range from 3,500' to 5,000', which was well within the efficiency range of the GOETHALS pumps. The closest section of the Virginia Beach shoreline in need of nourishment at the time the test could be scheduled was about 23,000' from Cape Henry. Thus, the total length of the discharge pipeline required to pump the material from the berthing facility to the eroded section of the Virginia Beach shoreline was estimated to range from 26,500' to 28,500'. The information developed during the Jacksonville test indicated that the efficiency of the centrifugal pumps on the GOETHALS dropped sharply as the length of the discharge pipeline reached and exceeded 8,000'. Therefore, in order to pump

the excavated material from the berthing facility to the eroded section of the Virginia Beach shoreline, two large booster pump units would have been required at two locations in the discharge pipeline. The procurement of this expensive equipment could not be justified for the test operation. Therefore, a proposal was made to the city officials to stockpile the excavated material along the Cape Henry shoreline for subsequent transfer to the Virginia Beach shoreline by trucks. Based on the urgent need for the nourishment of the eroded shoreline and an estimated production quantity that would provide a three year supply of material, the City of Virginia Beach officials requested that the Corps of Engineers proceed with the project during October 1974. The city officials also requested that arrangements be made to place as much of the material as possible above the high water line so that they could arrange to transport the material from the stockpile area to the eroded shoreline by trucks or other means.

Fort Story, a U. S. Army military reservation, is located along the Cape Henry shoreline. Arrangements were made with the Commander of this amphibious training installation to pump the excavated material along a 2,500' stretch of the reservation over a width of about 500'. In addition, the Commander agreed that the stockpile of material could remain along the shoreline for several years so that the

transfer of the material to the Virginia Beach shoreline could be accomplished as the need developed.

Test Operations

Positioning of DeLong Pier Barge and MB-2. During the period of July 29 to September 13, 1974, a series of test installations were conducted. At the outset, attempts were made to position and elevate the barge in several locations directly opposite the stockpile area of the Cape Henry shoreline and about 1,000' offshore of the beach. In the first test, the ten spuds of the DeLong Pier Barge were dropped to obtain initial penetration into the bottom material. Two of the spuds penetrated to a depth that required emergency procedures to prevent the spuds from sinking past the point that they could be retrieved with the pneumatic jacks. This test and several others in the area closest to the shoreline indicated that the bottom materials would not provide the friction factor needed to elevate the barge above the water surface.

After a series of unsuccessful tests, a site about 1,100' offshore of the beach and about 2,700' east of the Cape Henry shoreline proved to be suitable. The barge was then elevated about 5' above the mean low water surface at this location, which was 2.5 miles from the dredging zone.

On September 27, the MB-2 was towed from Philadelphia to Little Creek inlet and preparations made for placing it

next to and on the seaward side of the DeLong Pier Barge. On October 5, the MB-2 was towed to the site, coupled to the DeLong Pier Barge and the submerged flexible connection raised from the bottom and connected to the discharge pipeline on the MB-2. The mooring or berthing arrangement is shown in Figure 15.

Dredging and Unloading Operations[15]

With the berthing facility in position and about 3,850' of the discharge pipeline to the Cape Henry shoreline in place, the GOETHALS began dredging at 6:00 P.M. on October 6, 1974.

About twenty-four hours after the start of the test operation, strong winds developed from the northeast resulting in waves approaching a height of 6'. The following morning the equipment arrangement was inspected while the seas continued at a high level. During the inspection, it was noticed that the polyethelene fenders between the MB-2 and the DeLong Pier Barge were being badly deformed by the wave induced surging of the MB-2 against the DeLong Pier Barge. As the strong wind and heavy sea action continued through the day the GOETHALS discontinued dredging and anchored in the bay to ride out the storm. Meanwhile, the constant surging of the MB-2 caused the foam fenders to split and rupture. It was clear that these fenders were not suitable for the test operation. It was fortunate that the Commander

of the U. S. Coast Guard facility at Elizabeth City, North Carolina, agreed to the loan of two large Yokohama rubber-pneumatic fenders on short notice. These cylindrical fenders as shown in Figure 16, are 18' long and have a diameter of 8'. When inflated to a working pressure of 7.1 pounds per square inch, these fenders have an energy absorption capacity of 305 foot-kips and a reaction force of 245 kips at 50 percent deflection. The fenders were obtained and installed as the storm abated and the test operations were resumed during the afternoon of October 9. During this two-day period, there were 8 hours and 12 minutes of non-effective time for the GOETHALS while at anchor. The regularly scheduled lay-day for the GOETHALS to take on fuel, supplies and to make minor repairs also occurred during the storm period. However, this did not result in any lost-time because these activities took place at a protected location in Norfolk Harbor.

Even though winds over 25 MPH and waves approaching 6' in height were experienced several times during the test, there were no further fender problems experienced.

During the morning of October 11, a section of the pipeline on the shoreline separated while material was being pumped through the pipeline. Instead of waiting for the repairs to be made, the GOETHALS transported the remainder of the material to an offshore disposal area. By the time

the GOETHALS returned to the berthing facility with the next load of sand, the pipeline had been repaired.

Mechanical problems in the port centrifugal dredging pump developed on 12 October. Under normal circumstances, the GOETHALS would have undergone an annual overhaul in a shipyard prior to performing the test operation. However, due to the urgency of the Virginia Beach situation the annual overhaul had been rescheduled for a later date. The difficulty with the port pump posed a serious problem. Not only did it result in being able to dredge with only one pump, it was not possible to pump out the hopper since this operation requires that both pumps be utilized in a series configuration. Emergency repairs were made by the ship's crew during the night and the pumpout operation was resumed the following morning.

On October 14, the natural elements again became a deterrent factor to the operation; when about three-hours of non-effective time resulted due to an early morning dense fog.

During October 15, strong winds and the associated adverse sea conditions began to develop. Intermittent winds ranging from 20 to 30 MPH and seas from 4' to 5' were recorded through October 16 - 19. Nevertheless, the dredging and unloading operations continued without interruption.

During the remainder of October only a few minor delays were experienced. The yardage measured in the hoppers

of the GOETHALS did not compare to the in-situ volume of material since the pumped materials are diluted during the dredging process. Therefore, a conversion factor based on the type of material dredged was applied to estimate the volume of in-situ material removed from the waterway. The 349,206 cubic yards measured in the hopper were then adjusted by a factor of 80 percent resulting in an estimated in-situ yardage of 283,364 cubic yards.

As the operation continued into November there was a concern that the high level of production achieved in October could not be duplicated. Weather conditions were expected to worsen, the poor condition of both centrifugal pumps and the emergency repairs to the port centrifugal pump were the major factors contributing to the concern. However, the operation went along smoothly until November 4, when strong winds began to develop from the southwest. The winds gradually shifted to the northwest and by November 7 the heights of the seas were ranging from 4' to 6'.

After discharging a load of material on the morning of November 8, the GOETHALS remained moored to the MB-2 to protect the mooring facility from the heavy sea action. The sea conditions continued to worsen and the GOETHALS was forced to leave the mooring shortly after noon and proceed to an anchorage area in the bay. During the storm, winds in gusts up to 66 MPH were recorded. These were extreme

conditions and there was apprehension that the fenders would fail and the MB-2 severely damaged. However, the Yokohama rubber-pneumatic fenders performed well during the storm and neither the MB-2 or the DeLong Pier Barge were damaged. In addition, the submerged flexible connection, which had been a constant source of trouble during the Sea Girt test, survived the storm conditions without any damage. The non-effective time experienced during the storm amounted to 8-hours and 45-minutes.

Although strong winds and adverse sea conditions occurred intermittently throughout the remainder of the test operation the only delay due to the natural elements occurred over a 7-hour period between November 19-20. Based on production rate estimates and the poor condition of the port centrifugal pump, it was decided to conclude the test operation on the morning of November 25. At 5:30 A.M. on Thanksgiving morning the 174th load was discharged to the Cape Henry stockpile.

The yardage of 361,312 determined by physical measurements was adjusted by a factor of 80 percent resulting in an estimated in-situ yardage of 289,050 for November 1974. A map showing the stockpile area, the discharge pipeline and the berthing facility is shown in Figure 17.

During the morning of November 25, as another storm began to develop, the MB-2 was towed to a protected area in

the Little Creek inlet. By late afternoon, gale winds were occurring again. Thus, the decision to end the operation during the morning of November 25 had been a wise choice.

Summary

A summary of the effective time, production and non-effective time elements during the course of the October 6 through November 25 test operation is shown in Table 10. The effective time amounted to 86.2 percent. The improvement in the effective time over the Jacksonville effective time percentage of 83.2 percent was considered to be due to three factors. The use of the DeLong Pier Barge provided a fixed and stable berthing facility. The use of the Yokohama rubber-pneumatic fenders prevented damage to the submerged flexible connection and the MB-2. In addition, the experience gained during the Sea Girt and Jacksonville tests was a beneficial factor.

The total yardage measured in the hopper during the test was 710,518 cubic yards. Based on an adjustment factor of 80 percent, the estimated total volume of in-situ material placed on the beach during the test amounted to 572,414 cubic yards.

The length of the 28-inch discharge pipeline at the beginning of the test was 3,850' and the maximum length of the discharge pipeline was 4,690'.

As in the case of the Jacksonville test, scheduling the test operation in conjunction with maintenance dredging of a navigation channel provided a dual, navigation-nourishment, benefit. In addition, much of the time lost during the unloading operations was used in dredging the Thimble Shoal Channel and carrying the material to a disposal site in the Atlantic Ocean. During the test period, thirty-six hopper loads of material totalling 135,950 cubic yards were disposed of in this way. The effective time during this operation was also high -- 80 percent.

A sand dike was constructed with front-end loaders and bulldozers since this was a stockpiling operation rather than a conventional beach nourishment operation. The dike, constructed parallel to the shoreline to retain as much of the slurry on the shoreline as possible, is shown in Figure 17.

Surveys of the shoreline made before and after the test operation indicated that about 452,000 cubic yards or 79 percent of the estimated in-situ volume of 572,414 cubic yards pumped to the shoreline remained on the beach above the mean high water line.

The estimated cost of the project was $1,230,000 and the actual cost was $1,353,816 as indicated in Table 11. This resulted in an actual unit cost per cubic yard of $2.37 for the 572,414 cubic yards delivered to the beach and $3.00 per cubic yard for the 452,000 cubic yards of material

retained above the mean high water line. The estimated unit cost per cubic yard was $2.15 and $2.72 respectively. The major factor contributing to the higher unit costs per cubic yard was due to the extent of the structural modifications required to prepare the MB-2 for operation in an exposed area. Another factor, which was unexpected, was the need to modify Mooring Barge-1 so that it could be utilized for another operation for which the MB-2 would have been assigned.

The cycle time for the disposal of the material in the offshore location was about 8 percent greater than the cycle time for discharging the material to the beach. Based on the average cubic yards per effective work-day basis, the production rate during the test operation was 12 percent greater than the production rate while hauling the material to the disposal site in the Atlantic Ocean. Applying these factors to the production and time elements, and deleting all of the costs associated with the unloading operation, the unit cost for hauling the in-situ volume of material from the Thimble Shoal channel to the disposal area in the offshore zone would have been about $2.06 per cubic yard. Thus, in a conventional beach nourishment operation, the additional cost required to deliver the material to the shoreline was about thirty-one cents per cubic yard and about ninety-four cents per cubic yard for the stockpiling operation. If it had been possible to schedule another

test operation immediately and thus reduce the design and modification costs by one-half, the cost attributable to the test operation would have been significantly less.

The test results indicated that the docking and unloading operations could continue as long as the waves were less than 6' in height. The test also proved that the berthing arrangement and submerged flexible connection could withstand seas with heights ranging from 8' to 10' and winds of 66 MPH.

The test was considered a success by Corps of Engineers personnel and the officials of the City of Virginia Beach were most appreciative of the results obtained during an emergency situation.

SUMMARY

The results of the test operations at Sea Girt in 1966, Jacksonville and Virginia Beach in 1974 proved that the seagoing, self-propelled, hydraulic, hopper dredge was suitable to excavate material in the offshore zone and deliver the material to eroded beaches. The test indicated that the hopper dredge GOETHALS was able to operate under severe sea and weather conditions.

The test operation at Sea Girt, New Jersey, was only a qualified success. The effective time rate of 54 percent for the operation was low due to extensive equipment failures, the mooring barge being swept ashore during a storm

and the storm and fog conditions which prevailed during the latter part of the operational period.

The test at Jacksonville, Florida, was a success. The effective time rate of 83.2 percent was a considerable improvement over the initial test. In spite of the fact that the total length of the discharge pipeline was over twice the length of the pipeline used at Sea Girt, the operational and equipment problems were minimal.

The test at Virginia Beach, Virginia, was also a success even though it was planned and initiated in a brief period. The effective time rate of 86 percent was the highest of the three tests. In addition, the berthing arrangement proved to be suitable for severe storm and wave conditions.

The tests proved that the design features installed on hopper dredges have resulted in a type of equipment that can successfully, and within a reasonable cost range, provide materials from the offshore zone that are suitable for general construction and beach-nouishment requirements.

Chapter 5 will include an analysis of the operational conditions, equipment performance and the production and cost information presented in this chapter.

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Chapter 5

ANALYSIS OF TEST DATA

SEA GIRT TEST

Site Selection

The Sea Girt site was selected because the mooring arrangement and the docking and unloading operations would be exposed to severe storm and wave action.

The shoreline was badly eroded. In addition, the state officials of New Jersey supported the project and agreed to the usage of state lands as a staging area for the installation of the submerged pipeline and for the storage of equipment.

Dredge Selection

Two seagoing, self-propelled, hydraulic hopper dredges were equipped with a direct pumpout capability, the COMBER and the GOETHALS, at the time the test was scheduled. The GOETHALS was selected for the test since its hopper capacity of 6,422 cubic yards is about 82 percent greater than the 3,524 cubic yard capacity of the COMBER and the power available to the centrifugal pumps was about the same on each of the dredges.

The GOETHALS performed well throughout the test and proved to be suitable for continued operation under

severe storm conditions. The GOETHALS non-effective time, attributable to the natural elements, was due to dense fog that prevented the movement of any vessels in the area; and the rolling and pitching actions of the MB-2 when the heights of the waves approached and exceeded 6'.

The GOETHALS production rates during the test operation were comparable to the production estimates prepared during the planning phase.

Mooring Arrangement

Anchors and wire cables were used to hold the mooring barge in position. This arrangement resulted in the MB-2 moving in an elliptical pattern depending upon the wind and wave action. The area of movement was large, about 34' in a direction parallel to the beach and about 90' in an onshore-offshore direction.

The positioning of the MB-2, using anchors and wire cables, led to several operational problems:

Even though many attempts were made, it was not possible to reduce the area of movement to lesser dimensions than indicated above. Actually, it was a difficult job to restrain the barge within these limits.

The large movement pattern of the MB-2 resulted in a series of equipment difficulties in the submerged flexible connection, the ball-joints and the pipeline connections.

The pitch and roll characteristics of the MB-2, as the wave heights increased, made it difficult for the GOETHALS to dock and unload the material to the beach.

The placement and maintenance of the ten anchors required to hold the MB-2 in position was time-consuming and expensive.

The anchoring system was not adequate to withstand the effects of a severe storm, which led to the MB-2 being swept ashore. If quick action had not been taken by the shoreline crew, the barge would have been severely damaged on a nearby rock groin. Further, there was the possibility of losing the vessel by its being buried by the action of the surf.

There was the chance that the propellers of the GOETHALS could have been entangled in one of the wire cables leading to an anchor on the off-shore side of the MB-2.

In the overall, the use of anchors and wire cables to moor the MB-2 in the Atlantic Ocean was only marginally successful.

Use of Spuds on Mooring Barge (MB-2)

The use of spuds to position and elevate the MB-2 would have prevented many of the operational and equipment difficulties experienced with the submerged flexible connection, the ball joints and the pipeline connections

on the MB-2. However, the MB-2 is not equipped for self-elevation.

The repeated attempts to position the floating MB-2 on spuds failed because the rolling and pitching action of the barge caused the spuds to bind in their guide wells through the hull of the barge. The binding action caused the spuds to be slowly forced into the bottom material to the point that retrieval was difficult. In addition, the binding and racking action of the spuds led to some damage in the structural support members of the guide wells. Therefore, the use of spuds on the MB-2 was not practicable in an offshore location.

Alignment of the MB-2

The alignment of the MB-2 parallel to and about 2,000' from the shoreline proved to be adequate for the GOETHALS to approach and dock alongside on the seaward side of the barge.

Several other alignments were tested and the position parallel to the shoreline was the most effective. Surprisingly, an alignment perpendicular to the beach, which was initially considered to be the best alignment, resulted in the greatest rolling and pitching of the barge.

Submerged Flexible Connection

The flexible connection proved to be inadequate to provide for the movement pattern and the rolling and

pitching of the MB-2. When the barge moved to the outer limits of the elliptical pattern, or just outside the pattern, due to stretched or loosened wire cables, the mechanical elements such as the swivels and ball-joints failed. In retrospect, the flexible connection should have been designed with more strength and for a larger movement pattern. A significant portion of the non-effective time attributable to the MB-2 was due to the problems with the flexible connection components.

Discharge Line

The submerged steel discharge pipeline, with a 28-inch diameter and a length of 2,000', did not present any operational problems nor did the pipeline installed along the shoreline.

The minimum discharge pipeline length was 2,660' and the maximum length of the discharge pipeline was 4,250'.

Test Operations

Effective Time. The effective time rate of 54 percent for the project was much lower than the estimated rate of 75 percent.

A summary of the effective time percentages for the various operational elements is presented in the following table. The information in this table was extracted from Table 6.

Table 12

Summary of Effective Time Percentages -- Sea Girt

To Cut	Pumping & Turning	To MB-2	Docking & Undocking	Pumpout	Total
3	15	6	3	27	54

Source. Records, Corps of Engineers District, Philadelphia, Pennsylvania., (1966)

The percentages of the effective time required to travel to the dredging area, To Cut, and to the mooring facility, To MB-2, compared favorably with the estimates.

The percentage of the effective time required for the GOETHALS docking and undocking operations was the same as the estimated percentage.

The percentages of the effective time applied to the pumping/turning and pumpout operations were considerably less than the estimated percentages.

Non-Effective Time. A summary of the non-effective time percentages is presented in the following table. The information in the table was extracted from Table 6.

Table 13

Summary of Non-Effective Time Percentages -- Sea Girt

Fuel & Supplies	Anchor & Transiting	Natural Elements	MB-2	Repairs & Miscl.	Total
5	9	13	15	4	46

Source. Records, Corps of Engineers District, Philadelphia, Pennsylvania., (1966)

The percentages of the non-effective time needed to take on fuel and supplies and for minor repairs were comparable to the estimated percentages.

The time required for the GOETHALS to be at anchor and the time required to transit from the anchorage to the dredging site were excessive due to adverse weather conditions. In addition, a large portion of the high percentage of non-effective time attributable to the natural elements was due to the violent rolling and pitching of the MB-2, which prevented the GOETHALS from docking and unloading.

The non-effective time of 15 percent due to the rolling and pitching of the MB-2 and the associated equipment failures in the flexible connection and the pipeline connections on the MB-2, was considerably greater than the estimated percentage. This was largely due to the fact that the anchor and wire cable mooring arrangement permitted the MB-2 to surge over a large area.

Production. During the 18.7 days of the test, fifty-two hopper loads, consisting of 250,093 cubic yards of material were pumped to the beach. A summary of the production elements of the test is presented in the following table. The information in the table was extracted from Table 6.

Table 14

Summary of Production Elements -- Sea Girt

Average Cubic Yards Per Load	Average Loads Per Day	Average Cycle Time Per Load (Minutes)	Pumpout/ Pumping & Turning Ratio	Average One-Way Haul/Miles
4,809	2.8	277.5	1.8	1.5

Source. Records, Corps of Engineers District, Philadelphia, Pennsylvania., (1966)

The average cubic yards per hopper load was about 75 percent of the hopper capacity of the GOETHALS and considerably higher than the estimated average hopper load of 4,500 cubic yards. Two factors are considered to have resulted in the high percentage hopper loading. First, the pumping machinery was in excellent condition, Secondly, the material removed from the offshore borrow area had a high voids ratio and was easier to excavate than expected.

The average loads per day and the pumpout to pumping ratio were much less than estimated due to the mechanical problems with the submerged flexible connection and the ball-joints and pipeline connections on the MB-2. In addition, the production rate was affected adversely by the difficulties experienced in the docking and undocking operations due to wave action.

The pumpout to pumping ratio of 1.8 to 1.0 was very poor. This was the first operation which required the discharge of a large volume of sand through a long

submerged pipeline. Therefore, an unusual level of caution was exercised to avoid plugging the submerged pipeline of 2,000'. If the pipeline had become plugged it would have been necessary to pull the entire pipeline to the shoreline, dismantle the line and then reposition the pipeline. This would have been a time-consuming and expensive repair item. Therefore, in order to avoid this problem, a large amount of dilution water was introduced into the centrifugal pumps, which reduced significantly the effectiveness of the pumpout operation. In retrospect, too much dilution water was directed into the centrifugal pumps. However, from a positive viewpoint, the experience gained during this test resulted in more efficient results during the subsequent tests.

The average cycle time per load was comparable to the planning estimate. However, the large percentage of time lost due to the natural elements and the problems associated with the submerged flexible connection and other equipment limited the number of cycles that could be made.

Cost. The total cost of the project was $680,170., as compared with an estimated total cost of $700,000.

The cost per cubic yard of material delivered to the beach was $2.72 as compared with the estimated unit cost of $2.00.

The average cost for obtaining material from onshore

sites at the time the test was performed was about $3.50 per cubic yard.

<u>Summary</u>

The operation was only a qualified success. The total effective time rate of 54 percent was much less than the estimated 75 percent.

Extensive equipment problems and failures were a major factor in contributing to the low effective time percentage.

A lack of experience in this type of operation resulted in a poor performance rate.

There were an unusual number of storms during the test operation. The resultant wind and wave action resulted in the MB-2 being swept ashore, difficulties in the docking and undocking operation and the cessation of all operations when the waves approached and exceeded a height of 6'.

JACKSONVILLE TEST

<u>Site Selection</u>

A site in the lower estuary of the St. Johns River was selected to determine the efficiency of the operation in a semi-protected area rather than in the open sea.

A long discharge pipeline would be required to deliver the excavated material to the eroded section of

the beach south of the inlet.

The site would permit the realization of a dual benefit, in that the material excavated from a navigation channel would be utilized to nourish an eroded beach.

The nourishment of the Kathryn Abbey Hanna State Park shoreline would provide an improved facility for use by the public.

State officials of Florida supported the project.

Dredge Selection

Based on the satisfactory performance of the GOETHALS during the Sea Girt test, this dredge was selected for the test operation.

The primary consideration in the dredge selection was the hopper capacity. The GOETHALS capacity exceeded that available on the COMBER, and the McFARLAND which was constructed in 1967, by a factor of almost two to one.

Mooring Arrangement

Spuds, supplemented by two anchors on the shoreward side of the mooring barge were used to position the MB-1.

This mooring arrangement kept the MB-2 in a fixed position which eliminated most of the equipment failures experienced with the anchor and wire cable mooring arrangement.

The use of spuds, supplemented by only two anchors, proved to be suitable for use in a semi-protected area.

Alignment of the MB-1

The mooring barge was positioned generally parallel to and as close as possible to the south jetty. This location was chosen since it would provide optimum protection along with a large enough area to provide easy access for the GOETHALS during the docking operations.

Other factors which related to the location and alignment of the MB-1 were the water depths and the bottom materials. Consideration of these factors was necessary to assure that the spud lengths on the MB-1 were adequate and that a reasonable penetration depth into the bottom material could be achieved.

The alignment of the MB-1 proved to be suitable.

Flexible Connection

One end of the MB-1 was within 30' of the jetty slope. Therefore, a trestle section was constructed between the deck of the MB-1 and the jetty. The discharge line from the MB-1 to the shoreline was placed on the trestle and ball-joints installed to provide for the vertical movement of the barge due to the tidal range.

The flexible connection and trestle section proved to be suitable.

Discharge Line

The steel discharge pipeline, with a 28-inch diameter, did not present any operational problems.

The minimum discharge pipeline length was 3,000' and the maximum length of the discharge pipeline was 8,200'.

Test Operations

Effective Time. The effective time rate of 83 percent was greater than the estimated rate of 75 percent.

A summary of the effective time percentages for the various operational elements is presented in the following table. The information in this table was extracted from Table 9.

Table 15

Summary of Effective Time Percentages -- Jacksonville

To Cut	Pumping & Turning	To MB-1	Docking & Undocking	Pumpout	Total
5	15	6	3	54	83

Source. Records, Corps of Engineers District, Jacksonville, Florida., (1974)

The percentages of the effective time required to travel to the dredging area, To Cut, and to the mooring facility, to MB-1, were slightly more than the estimates prepared for these items during the planning phase. This was due to the stratified currents in the estuary and the need to coordinate these operations with maritime traffic

utilizing the navigation channel.

The percentage of the effective time required for the GOETHALS docking and undocking operations was about the same as the estimated percentage.

The percentages of effective time applied to the pumping/turning and pumpout operations were considerably greater than the estimated percentages.

Non-Effective Time. A summary of the non-effective time percentages is presented in the following table. The information in the table was extracted from Table 9.

Table 16

Summary of Non-Effective Time Percentages -- Jacksonville

Fuel & Supplies	Anchor & Transiting	Natural Elements	MB-1	Repairs & Miscl.	Total
5	1	2	2	7	17

Source. Records, Corps of Engineers District, Jacksonville, Florida., (1974)

The percentage of the non-effective time needed to take on fuel and supplies was about the same as the estimated percentage.

The percentage of time required for repairs was somewhat greater than the estimated percentage. However, this was understandable due to the discharge pipeline length and the high pressures generated within the pipeline.

The percentages of the non-effective time required

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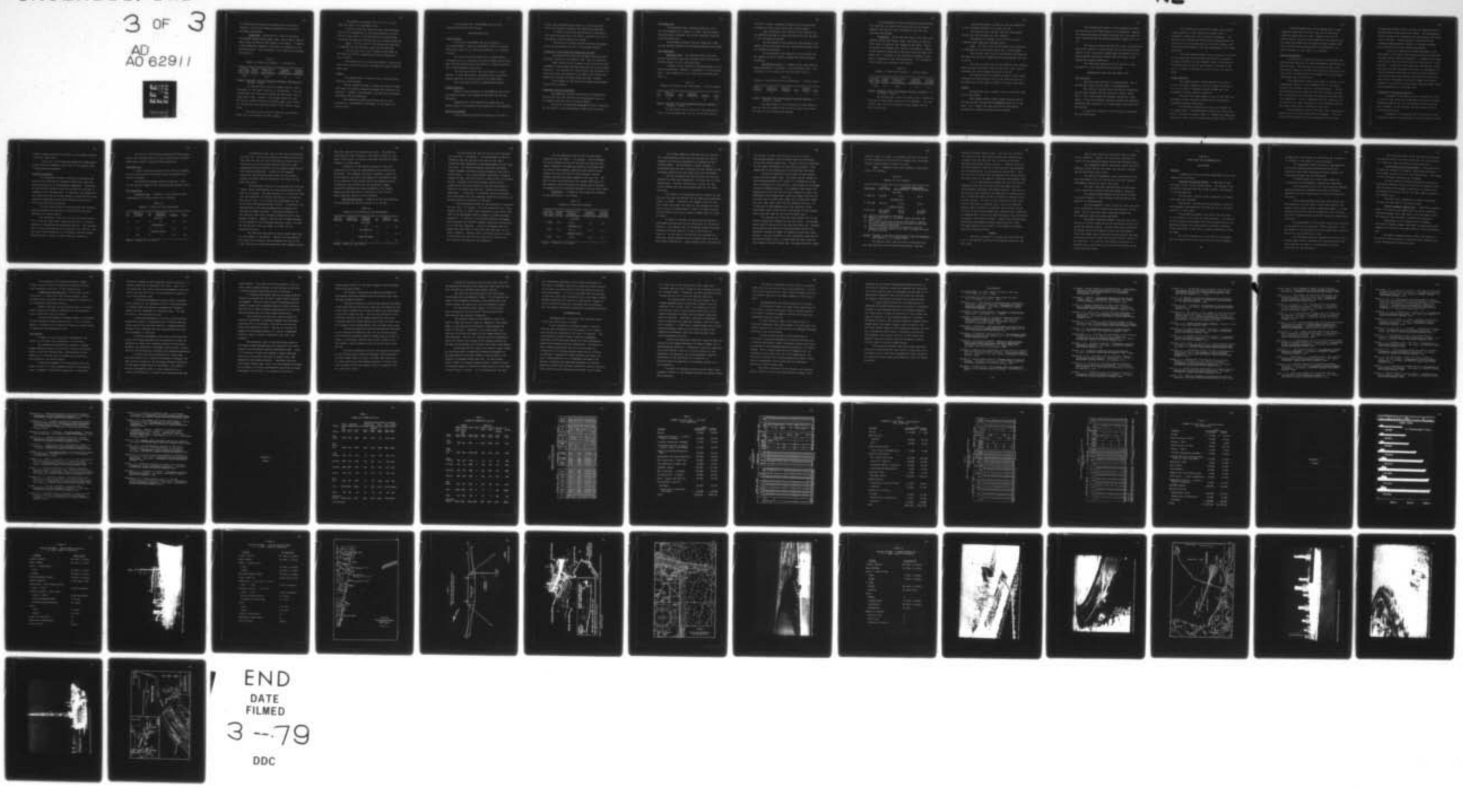

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for anchoring and transiting; delays due to the natural elements; and the MB-1 were considerably less than the estimated percentages.

Production. During the 37.3 days of the test, one hundred twenty-seven hopper loads, consisting of 400,170 cubic yards of material were pumped to the beach. A summary of the production elements of the test is presented in the following table. The information in the table was extracted from Table 9.

Table 17

Summary of Production Elements -- Jacksonville

Average Cubic Yards Per Load	Average Loads Per Day	Average Cycle Time Per Load (Minutes)	Pumpout/ Pumping & Turning Ratio	Average One-Way Haul/Miles
3,201	3.5	338.2	3.5	1.2

Source. Records, Corps of Engineers District, Jacksonville, Florida., (1974)

The average cubic yards per hopper load was about 50 percent of the hopper capacity of the GOETHALS. This was considerably less than the estimated average hopper load of 4,500 cubic yards. However, the average number of loads per day was greater than the estimated number, which offset to a large extent the negative effect of the smaller hopper loads.

The average cycle time per load was considerably better than the estimate for this element.

The pumpout to pumping ratio of 3.4 to 1.0 was about the same as the estimated ratio.

Except for the four occasions when the discharge pipeline was plugged due to the large quantity of oyster shells in the slurry, little difficulty was experienced in pumping the material through the long discharge pipeline.

Cost. The total cost of the project was $919,160, as compared with an estimated total cost of $894,500.

The cost per cubic yard of material delivered to the beach was $2.30 as compared with the estimated unit cost of $2.24.

The average cost for obtaining material from onshore sites at the time the test was performed was about $3.00 per cubic yard.

Summary

The operation was a success, with a high effective time rate of 83 percent.

On one occasion the MB-1 drifted away from the jetty and broke the pipeline connection between the barge and the shoreline. However, few equipment problems were experienced throughout the test operation.

The experience gained during the Sea Girt test resulted in a considerable improvement in the pumpout to pumping ratio.

For the most part, the weather was mild and favorable during the test period.

VIRGINIA BEACH TEST

Site Selection

The site in Chesapeake Bay was selected to determine whether a mooring arrangement could be provided that would result in an efficient operation in an exposed location.

The City of Virginia Beach was in urgent need of assistance due to a high rate of erosion during the previous year and the unavailability of material in nearby estuaries due to environmental constraints.

The site would permit the realization of a dual benefit, in that the material excavated from a navigation channel would be utilized to nourish an eroded beach.

City and State officials supported the project.

Dredge Selection

Based on the performance of the GOETHALS during the two previous tests, this dredge was selected for the test operation.

Comparability of the production capability was another factor contributing to the selection of the GOETHALS.

Mooring Arrangement

A self-elevating DeLong Pier Barge was utilized to

assure that the barge would remain in a fixed position during the docking, unloading and undocking operations.

In order to avoid the modification of the DeLong Pier Barge borrowed from Fort Eustis, the MB-2 was used in conjunction with the DeLong Pier Barge.

The DeLong Pier Barge and MB-2 mooring arrangement proved to be suitable for use in an exposed location.

Alignment of the DeLong Pier Barge and the MB-2

The DeLong Pier Barge and the MB-2 were positioned generally parallel to ana about 1,100' from the shoreline.

Other factors which related to the location and the alignment of the barges were the water depths and the bottom materials. Consideration of these factors was necessary to assure that the spud lengths on the DeLong Pier Barge were adequate to elevate the barge above the water surface.

The alignment of the DeLong Pier Barge and the MB-2 proved to be suitable.

Submerged Flexible Connection

The submerged flexible connection utilized during the Sea Girt test was modified and strengthened prior to its usage during the test at Virginia Beach.

The use of the modified submerged flexible connection did not result in any non-effective time during the test.

Discharge Line

The submerged steel discharge pipeline, with a 28-inch diameter and a length of 1,100', did not present any operational problems, nor did the pipeline installed along the shoreline.

The minimum discharge pipeline length was 3,850' and the maximum length of the discharge pipeline was 4,690'.

Test Operations

Effective Time. The effective time rate of 86 percent was greater than the estimated rate of 80 percent; and the highest rate of the three tests.

A summary of the effective time percentages for the various operational elements is presented in the following table. The information in this table was extracted from Table 11.

Table 18

Summary of Effective Time Percentages -- Virginia Beach

To Cut	Pumping & Turning	To MB-2	Docking & Undocking	Pumpout	Total
7	35	8	3	33	86

Source. Records, Corps of Engineers District, Norfolk, Virginia., (1974)

The percentages of the effective time required to travel to the dredging area, To Cut, and to the mooring

facility, To MB-2, compared favorably with the estimates prepared for these items during the planning phase.

The percentage of the effective time required for the GOETHALS docking and undocking operations was the same as the estimated percentage.

The percentage of the effective time devoted to the pumping and turning operation was considerably greater than the estimated percentage.

The percentage of the effective time required for the pumpout was only slightly greater than the estimated percentage.

Non-Effective Time. A summary of the non-effective time percentages is presented in the following table. The information in the table was extracted from Table 11.

Table 19

Summary of Non-Effective Time Percentages -- Virginia Beach

Fuel & Supplies	Anchor & Transiting	Natural Elements	MB-2	Repairs & Miscl.	Total
5	3	1	1	4	14

Source. Records, Corps of Engineers District, Norfolk, Virginia., (1974)

The percentages of the non-effective time needed to take on fuel and supplies and for minor repairs were about the same as the estimated percentages.

The percentages of the non-effective time required for anchoring and transiting; delays due to the natural elements and the MB-2 were considerably less than the estimated percentages.

Production. During the 48.2 days of the test, one hundred seventy-four hopper loads, consisting of 572,414 cubic yards of material were pumped to the beach. About 79 percent, or 452,000 cubic yards of the material pumped to the shoreline remained on the beach above the mean high water line. A summary of the production elements of the test is presented in the following table. The information in this table was extracted from Table 11.

Table 20

Summary of Production Elements -- Virginia Beach

Average Cubic Yards Per Load	Average Loads Per Day	Average Cycle Time Per Load (Minutes)	Pumpout/ Pumping & Turning Ratio	Average One-Way Haul/Miles
4,083	3.6	343.9	0.9	2.5

Source. Records, Corps of Engineers District, Norfolk, Virginia., (1974)

The average cubic yards per hopper load of 4,083 was about 64% of the hopper capacity of the GOETHALS. This was slightly less than the estimated average hopper load of 4,300 cubic yards.

The average number of loads per day was comparable to the estimated average of 3.5 loads per day.

The average cycle time per load was considerably greater than the estimate for this element.

The pumpout to pumping ratio of 0.9 to 1.0 was slightly better than the estimated ratio.

Cost. The total cost of the project was $1,353,316, as compared with an estimated total cost of $1,230,000.

The cost per cubic yard of the material delivered to the beach was $2.37 as compared with the estimated unit cost of $2.15.

The cost per cubic yard of the material that remained above the mean high water line was $3.00 per cubic yard as compared with the estimated unit cost of $2.75.

The average cost for obtaining material from nearby estuaries and from onshore sites at the time the test was performed was in the range of $2.50 to 5.00 per cubic yard.

Summary

The operation was a success, with an effective time rate of 86 percent.

Even though several severe storms occurred during the test period, the mooring arrangement proved to be adequate. As a result, the time lost during the docking, unloading and undocking operations was minimal.

The polyethylene fenders utilized between the MB-2 and the DeLong Pier Barge proved to be inadequate. However, the Yokohama fenders performed extremely well even when the winds reached 66 MPH and the wave heights ranged from 8' to 10'.

The need to proceed with the test prior to performing the annual overhaul on the GOETHALS led to difficulties and repairs to the centrifugal dredge pumps throughout the test. These problems adversely effected the efficiency of the pumping and pumpout operations.

The experience gained during the two prior tests resulted in a very high effective time rate.

COMPARISON OF DATA FOR THE THREE TESTS

Site Selection

Two sites were selected in exposed waters, one in the Atlantic Ocean and the other in Chesapeake Bay.

One site was located within the jetties protecting the entrance channel into the estuary of the St. Johns River. This site offered the greatest operational advantages, in that the dredging, docking, loading and undocking operations were protected to a large degree from storm and wave action.

In each case, state and local officials supported the test operations.

The Jacksonville and Virginia Beach sites offered a dual benefit, in that material excavated from a navigation channel was used for beach nourishment. The Sea Girt site offered the opportunity of demonstrating the feasibility of excavating material from the offshore zone and utilizing the material for the nourishment of an eroded shoreline.

The sites were selected to be as typical as possible of the conditions existing along the Atlantic coastline. The haul distances from the dredging areas to the mooring facilities were varied for this reason; 1.5 miles at Sea Girt, 1.2 miles at Jacksonville and 2.5 miles at Virginia Beach.

Dredge Selection

The seagoing hopper dredge GOETHALS was used in each of the tests, because it has the largest capacity of any of the Corps of Engineers hopper dredges which are equipped for direct pumpout operations.

The use of the same dredge in each of the tests was desirable so that the basic operational and production parameters would be consistent.

The GOETHALS performed well during all phases of the three tests. The experienced officers and crew of the vessel displayed an unusual level of interest and competence, which was a major factor contributing to the success of the

The centrifugal pumps of the dredge were in good condition during the first two tests and in very poor condition during the last test. However, the test at Virginia Beach could not be delayed due to the urgent need for beach nourishment and the adverse winter weather that would have been experienced after the completion of an annual overhaul of the vessel in a shipyard.

Mooring Arrangement

The use of an anchoring system for positioning the mooring barge resulted in a poor performance rate during the Sea Girt test. The failure of the system during a storm resulted in damage to the MB-2 and could have resulted in the loss of this valuable piece of equipment with an estimated replacement cost of $5 million.

The combination usage of the spuds on the MB-1, with supplemental anchors on the shoreward side of the barge, proved to be suitable for use in protected waters. During the Jacksonville test there was only one instance that the MB-1 drifted from its position and broke the discharge pipeline connection. Since a submerged flexible connection was not used at this site the repairs to the discharge pipeline were made quickly with a minimum of lost time.

The combination usage of the MB-2 with a DeLong Pier Barge proved to be the best mooring arrangement. The only difficulty resulting from this arrangement was with the

polyethylene fenders used to cushion the surging action of the MB-2 against the DeLong Pier Barge. The polyethylene fenders proved to be inadequate and failed during the early part of the test. After they were replaced with the Yokohama rubber-pneumatic fenders, no further problems were experienced with the mooring arrangement.

The use of a DeLong Pier Barge, equipped in the same manner as the MB-2, would provide the best operational and least costly mooring arrangement. A barge of this type would assure that the mooring facility remained in a fixed position. In addition, with the barge elevated just above the water surface, the barge would act as a breakwater and permit unloading operations to continue on the shoreward side of the barge under adverse wind and wave conditions. With such an arrangement the hopper dredge could remain berthed at the facility during severe adverse weather rather than proceeding to an anchorage area.

Alignment of the Mooring Facility

Alignment of the mooring facility parallel to and as close to the shoreline as possible to provide a minimum flotation depth of 30' for the GOETHALS proved to be the best alignment in the offshore zone at the Sea Girt and Virginia Beach sites.

Alignment of the mooring facility parallel to the navigation channel and perpendicular to the entrance to the

Atlantic Ocean proved to be suitable in the estuary portion of the St. Johns River.

The use of a self-elevating DeLong Pier Barge would permit optimal alignment at any site for the reasons given in the preceding paragraph.

Flexible Connection

The submerged flexible connection used during the Sea Girt test resulted in extensive repairs and lost time due to the failure of the equipment components. The design of the flexible connection did not provide for the area of movement of the floating MB-2. In addition, the elements of the connection were not sturdy enough to withstand the forces exerted on them when the mooring barge was pitching and rolling during storm conditions.

The unit used at Sea Girt was modified and strengthened and proved to be entirely suitable during the test operation at Virginia Beach.

The proximity of the MB-1 to the south jetty at the site in the St. Johns River permitted the use of a trestle section to accommodate the discharge pipeline. This arrangement is desirable whenever site conditions will permit, since the repair and maintenance of a discharge pipeline located above the water surface is easier and less expensive.

The use of a self-elevating DeLong Pier Barge would permit the increased usage of trestle section type supports which would result in more efficient operations.

Discharge Line

A steel discharge pipeline, with a 28-inch diameter was used during each of the three tests and proved to be entirely suitable.

The minimum discharge pipeline length was 2,660' and the maximum length of the discharge pipeline was 8,200'.

Test Operations

Effective Time. A summary of the effective time percentages for the three tests is as follows:

Table 21

Summary of Effective Time Percentages

To Cut	Pumping & Turning	To MB	Docking & Undocking	Pumpout	Total
		SEA GIRT			
3	15	6	3	27	54
		JACKSONVILLE			
5	15	6	3	54	83
		VIRGINIA BEACH			
7	35	8	3	33	86

Source. Tables 12, 15, and 18

The effective time rate for the Sea Girt operation was very low. This can be explained to some extent by the fact that this was the first test and an unusual level of caution was exercised to make certain that the 2,000' submerged discharge pipeline did not become plugged during the unloading operations. Except for the pumpout operations, the effective time rates for this project compare favorably with the effective time rates for the other two tests.

The protected location of the Jacksonville site was a major factor contributing to a very high effective time rate of 83 percent. The haul distance of 1.2 miles for this test was comparable to the haul distance of 1.5 miles for the Sea Girt test. As a result the percentages for the To Cut and To MB operations were similar. In addition, the pumping/turning and docking/undocking percentages were the same for these two tests. The major difference in the effective time rates for these operations was in the pumpout category. However, this was due to the difference in the lengths of the discharge pipelines; 2,660' to 4,250' for the Sea Girt test and 3,000' to 8,200' for the Jacksonville test.

The effective time rate for the Virginia Beach test was the highest -- 86 percent. Taking into consideration the longer haul distance, the percentages for the To Cut, To MB, Docking and Undocking operations were somewhat better

than the rates for the two previous tests. The effective time trend for these features, indicated in Table 22, will make it much easier to forecast the time required for these elements in future tests.

Evaluation of the relative success of the test operations utilizing only the effective time rates can be misleading. For example, the type of material relates to the excavation rate and to the amount of the material that can be retained in the hopper during the dredging process. In addition, the condition of the centrifugal pumps, propulsion machinery and other equipment on the hopper dredge; and the operational conditions at the site are other important factors to be considered.

Non-Effective Time. A summary of the non-effective time percentage for the three tests is as follows:

Table 22

Summary of Non-Effective Time Percentages

Fuel & Supplies	Anchor & Transiting	Natural Elements	MB	Repairs & Miscl.	Total
		SEA GIRT			
5	9	13	15	4	46
		JACKSONVILLE			
5	1	2	2	7	17
		VIRGINIA BEACH			
5	3	1	1	4	14

Source. Tables 13, 16, and 19

The non-effective time for the Sea Girt operation was very high -- 46 percent. The percentages of the non-effective time for the fuel and supplies and repair categories were comparable to the percentages for the other two tests. The large percentages under the anchorage, natural elements and mooring barge categories were due to three factors. First, poor weather conditions, including storms and fog, prevailed during a large portion of the test period. Secondly, the large movement pattern led to extensive rolling and pitching of the MB-2 which made it difficult to conduct the docking, loading and undocking operations. In addition, a continuing series of problems were experienced with the submerged flexible connection unit and the pipeline connections on the MB-2.

The non-effective time for the Jacksonville operation was very low -- 17 percent. The semi-protected site in the estuary of the St. Johns River resulted in very little lost-time in the anchorage, natural elements and mooring barge categories. In addition, the improved mooring arrangement and the prevailing favorable weather conditions contributed to an efficient operation. The only percentage that was higher than the trend for the other two tests was for the repair category. However, with a discharge pipeline length of twice that for the other two tests the 7 percent for this item was considered to be reasonable.

The non-effective time for the Virginia Beach operation was the lowest -- 14 percent. The percentages of the non-effective time for the fuel and supplies and repair categories followed the trend for the other tests. In spite of poor weather conditions and several severe storms, the lost-time rate in the anchorage, natural elements and mooring barge categories was very low. The major factors contributing to the unusual efficiency of the operation were the DeLong Pier Barge type of mooring arrangement and the experience gained in the two prior tests.

Production. A summary of the production elements of the three tests is as follows:

Table 23

Summary of Production Elements

Average Cubic Yards Per Load	Average Loads Per Day	Average Cycle Time Per Load (Minutes)	Pumpout/ Pumping & Turning Ratio	Average One-Way Haul/Miles
		SEA GIRT		
4,809	2.8	277.5	1.8	1.5
		JACKSONVILLE		
3,201	3.5	338.2	3.5	1.2
		VIRGINIA BEACH		
4,083	3.6	343.9	0.9	2.5

Source. Tables 14, 17, and 20

The average number of loads per day was low and the pumpout/pumping ratio high for the Sea Girt test as compared with the test operations at Jacksonville and Virginia Beach. The difference in these elements is highlighted when the haul distances and the lengths of the discharge pipelines for the three tests are considered.

The haul distances for the Sea Girt test and the Jacksonville test were comparable; 1.5 miles and 1.2 miles respectively. The haul distance of 2.5 miles for the Virginia Beach test was much greater than for the other two tests.

The range of the discharge pipeline length for the Sea Girt test was the smallest of the three test operations; 2,660' to 4,250'. Therefore, the pumpout ratio for this test should have been less than for the Jacksonville test with a pipeline length range of 3,000' to 8,200' and the Virginia Beach test with a pipeline length range of 3,850' to 4,690'.

A factor to consider in evaluating the relative performance achieved during the three tests is the type of material. The pumping rate of the hopper dredge indicates whether the bottom material is easy or difficult to excavate. In the case of the Sea Girt and Jacksonville tests the average pumping time per hopper load was 65 and 60 minutes respectively. These pumping cycles indicate that

the material in both locations was easy to excavate. The average pumping time per hopper load was 133 minutes during the Virginia Beach test. However, the poor condition of both pumps throughout this test does not permit a fair comparison of the pumping cycle with the other two tests.

The type of material also relates to the average cubic yards per hopper load. The grain-size and weight of the excavated material will result in a difference in the rate of retention of the material in the hopper of the dredge during the dredging process. For example, even though the pumping cycles for the Sea Girt and Jacksonville tests were comparable, the average cubic yards per hopper load for the Sea Girt test of 4,809 cubic yards were considerably higher than the 3,201 cubic yards for the Jacksonville test. As in the case of the pumping cycle, the condition of the centrifugal pumps distorted the relationship of the average cubic yards per load for the Virginia Beach test.

The average cycle time per load reflects all of the various operational elements at the test sites. The average cycle time for the Sea Girt test was relatively low. However, the excessive non-effective time experienced during this operation limited the number of dredging cycles that could be made. The poor condition of the centrifugal pumps during the Virginia Beach test is evident when the cycle time for this project of 343.9 minutes and a discharge pipeline length

range of 3,850' to 4,690' are compared with the cycle time for the Jacksonville test of 338.2 minutes and a discharge pipeline length range of 3,000' to 8,200'.

Cost. A summary of the cost elements of the three tests is as follows:

Table 24

Summary of Cost Elements

Total Cost	Total Cubic Yards	Cost per Cubic Yard: Test Operation	Cost per Cubic Yard: Onshore Sources
	SEA GIRT		
$ 680,170	250,093	$2.72	$3.50
	JACKSONVILLE		
$ 919,160	400,170	$2.30	$3.00
	VIRGINIA BEACH		
$1,353,316	572,414 (1)	$2.37	$2.50 (3)
	452,000 (2)	$3.00	$5.00 (4)

(1) Material delivered to the beach.
(2) Material retained in a stockpile above the mean high-water line.
(3) Unit cost for material obtained from estuary sources. The use of these sources was discontinued in 1974 due to environmental constraints.
(4) Unit cost for the truck haul of material from the nearest available onshore site over an average distance of about 12 miles.

Source. Records, Civil Works Directorate, Corps of Engineers, Washington, D. C., (1966 & 1974)

The cost per cubic yard for each of the tests was less than the unit cost for obtaining material from the

nearest available onshore sites. The unit cost of $2.37 per cubic yard for the Virginia Beach test operation was slightly less than the unit cost of $2.50 for material obtained from nearby estuary sources. However, prior to the test operation, the use of the material from estuaries was discontinued due to environmental constraints. Thus, the unit cost of $2.37 must be compared with the $5.00 cost per cubic yard for the material obtained from onshore sites.

It is interesting to compare the cost of the test operations with the cost that would have been incurred using material obtained from onshore sources. The cost of the Sea Girt test operation was $680,000 as compared with a cost of $875,325 based on the utilization of material from onshore sources. The cost of the Jacksonville test operation was $919,160 as compared with a cost of $1,200,510 based on the utilization of material from onshore sources. The cost of the Virginia Beach test operation was $1,353,326 as compared with a cost of $2,862,070 based on the utilization of material from onshore sources. These costs indicate that these beach nourishment projects would have had a less favorable benefit to cost ratio if the material had been taken from onshore sources.

SUMMARY

The tests resulted in a lesser unit cost than the cost of the material available from onshore sources at the test sites.

Each of the tests were successful from an operational viewpoint. However, the efficiency improved as a result of the experience gained during the preceding tests.

The submerged flexible connection, which was barely adequate during the Sea Girt test, was entirely suitable during the Virginia Beach test.

The mooring arrangement, which contributed to the poor performance rate for the Sea Girt test was improved considerably during the latter two tests.

The test sites were representative of the operational conditions existing along the Atlantic coastline.

The hopper dredge GOETHALS proved to be suitable to excavate material in the offshore zone and deliver the material to eroded beaches.

The environmental factors of each of the sites were fully considered in the planning and the execution of the tests. Each of the tests were completed without any environmental complaint being registered.

The hopper dredging procedure involves the introduction of dilution water during the excavation process and during the pumpout process. As the excess water overflows the hopper during the dredging process and subsequently flows into deeper water along the coastline during the pumpout process only the larger and heavier materials remain on the shoreline. As a result, the quality of material is improved and is more effective in the stabilization of the eroded shoreline areas.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Research

A summary of the conclusions predicated on the study research is as follows:

Shortage of Sand and Gravel. A shortage of sand and gravel exists in the United States. The review of the literature indicated that the primary factors contributing to the shortage are:

The materials located in many estuaries and onshore areas have been depleted.

Legislation, including zoning ordinances, based on environmental considerations preclude the use of available materials in many areas.

The population growth of the nation has resulted in an increase in the usage of sand and gravel. In addition to the increased requirement for sand and gravel due to the population growth, the concentration of about 75 percent of the population in the coastal regions contributes to the shortage.

The rising standard of living with the associated need to construct new facilities such as streets, highways,

bridges and a wide variety of structures has resulted in an increase in the need for sand and gravel.

The remarkable recent increase in the demand for facilities associated with recreational activites, especially those that are water and beach related, has increased the need for sand and gravel.

Suitable materials in many areas cannot be utilized due to environmental concerns and objections.

The increasing size of the cities and the adjacent suburban areas has eliminated the usage of suitable materials which are located near or within the metropolitan areas.

The distance between the areas that contain suitable materials and the areas in which the materials are needed in the largest volume is becoming greater. In some cases, particularly along the coastlines, this situation has led to transportation costs that cannot be economically justified.

The development of the coastal regions has resulted in the erosion of the shoreline in many localities. The nourishment or the restoration of the eroded areas requires the use of vast quantities of sand.

The increasing need for offshore facilities such as nuclear power plants, petroleum off-loading and drilling facilities has resulted in a requirement for large quantities of sand and gravel.

The increasing trend in the creation of marshlands and upland habitat for birds and marine life has resulted in a need for large quantities of sand and gravel.

Availability of Sand and Gravel. Large quantities of material suitable for general construction and beach nourishment purposes exist in the offshore zone. The review of the literature indicated the following:

A sand inventory program conducted by the Coastal Engineering Research Center of the Corps of Engineers since 1964 indicates that enormous quantities of suitable sand and gravel exist within the 30' and 100' depth contours of the offshore zone.

The ocean floor sediments are widely distributed and thus are near many of the market areas.

Marine Equipment Capabilities. Significant improvements in the design and capabilities of marine equipment, including dredges, have been made in the past twenty years. The review of the literature indicated the following:

Improvements in the capabilities of dredges, particularly hopper dredges, have made it operationally and economically feasible to excavate material from the offshore zone.

The hopper dredging process reduces the degree of pollution in the excavation of materials from waterways due to the introduction of dilution water.

The seagoing, self-propelled hydraulic hopper dredge is best suited to withstand the adverse wind and wave conditions that occur in the offshore zone.

Condition of the Shoreline. The erosion of the shoreline is a large-scale and serious problem. About 20,500 miles of the total shoreline length of 84,300 miles are undergoing significant erosion.

About 2,700 miles of the shoreline have a critical rate of erosion and about 17,800 miles of the shoreline have a significant rate of erosion.

Periodic nourishment of eroded beaches is considered the best method for beach stabilization. It is a natural method, is aesthetically pleasing and permits a wide variety of commercial and recreational uses.

Test Results

A summary of the conclusions predicated on the results of the three test operations is as follows:

The seagoing, self-propelled, hydraulic, hopper dredge GOETHALS proved to be entirely suitable to excavate material from the offshore zone, transportation of the material to a location near the shoreline and delivery of the material to eroded beaches.

A mooring arrangement utilizing anchors and wire cables results in a large movement pattern of the mooring barge. Movement of the mooring barge over a large area

resulted in damage to the submerged flexible connection on several occasions and extensive lost time. Thus, it is concluded that this type of mooring arrangement, which was used at the Sea Girt site, is only marginally suited for use in the offshore zone.

A mooring arrangement utilizing spuds, supplemented by anchors on the shoreward side of a floating barge, is suitable when the docking, unloading and undocking operations are conducted in a protected area. This was the case in the Jacksonville test.

A mooring arrangement, utilizing a self-elevating DeLong Pier Barge in combination with a floating mooring barge proved to be the most effective. Rubber-pneumatic fenders of the Yokohama type are required when this type of arrangement is utilized.

A mooring arrangement, utilizing a self-elevating DeLong Pier Barge equipped with the necessary winches and machinery to couple the discharge pipeline of the hopper dredge to the pipeline on the barge, would provide a better facility for the docking, unloading and undocking operations.

A mooring facility consisting of a large buoy, multiple anchors and a flexible and buoyant discharge line that could be coupled to the discharge pipeline connection of the hopper dredge should be evaluated. This type of mooring arrangement, which is often referred to as a "single point mooring," is used to off-load petroleum from

super tankers. This type of facility permits a ship to swing freely around the buoy so that the bow of the ship is always pointed toward the crests of the waves.

A flexible and buoyant type of discharge pipeline should be evaluated for use with a barge type of mooring arrangement. The use of this type of discharge pipeline between a barge and a submerged pipeline might eliminate the need for a steel flexible connection unit of the type used during the Sea Girt and Virginia Beach tests.

The conditions at each test location should be carefully considered to determine whether the discharge pipeline can be installed on a trestle as was the case during the Jacksonville test. The use of a trestle to support the discharge pipeline, in lieu of a submerged pipeline, makes it easier to maintain and repair the pipeline.

The production rate of the centrifugal pumps on the hopper dredge GOETHALS declined rapidly as the total length of the discharge pipeline approached 8,000'. While it is possible to pump sand through a longer discharge pipeline by increasing the water to solids ratio, the production rate becomes marginal. Therefore, when two centrifugal dredge pumps, with a 30-inch diameter discharge, are arranged in a series configuration and driven by 6,000 horsepower are utilized it is necessary to utilize a

booster pump station, if the total length of the discharge pipeline exceeds 8,500'.

The docking, unloading and undocking elements of the pumpout operation become difficult and must cease when the wave heights exceed 6'.

The daily production rate for the material delivered to the beach during the Sea Girt test was the highest of the three tests; 250,093 cubic yards divided by 18.7 days equals 13,374 cubic yards per day. This was due primarily to the excellent condition of the pumping machinery, the short discharge pipeline length ranging from 2,660' to 4,250' and the unusually high average hopper load of 4,809 cubic yards.

The daily production rate for the material delivered to the Jacksonville Beach was the best of the three tests when the total discharge pipeline length range of 3,000' to 8,200' is considered; 400,170 cubic yards divided by 37.3 days equals a daily production rate of 10,728 cubic yards per day.

The daily production rate for the material delivered to the Virginia Beach shoreline through a total discharge pipeline length range of 3,850' to 4,690' was low due to the poor condition of the pumping machinery; 572,414 cubic yards divided by 48.2 days equals a daily production rate of 11,876 cubic yards.

In each of the tests, the cost per cubic yard for the material delivered to the beach was lower than the unit cost of material available from onshore sources.

The plans for executing each of the tests were coordinated with environmental groups. By considering the views of environmental interests, the projects were completed without any objections from environmental groups.

For the reasons given above, all of the tests were considered to be successful from the operational, environmental and economic viewpoints.

The trunnion elbows of the GOETHALS, which are used to lower the suction pipes or dragarms of the dredge pumps to the bottom of the waterway, extend beyond the sides of the ship. Therefore, very large fenders are required to cushion the impact of the dredge against the mooring barge. The use of a sliding trunnion arrangement, which will permit the storage of the dragarm assembly on the deck of the dredge will minimize the fender requirement.

During the past two years, an Industry hopper dredge was utilized under a competitive bidding arrangement to excavate material from the offshore zone and deliver the material to Rockaway Beach, New York. At the present (April, 1978), an Industry hopper dredge is being utilized in the same manner to nourish an eroded section of the beach in Duval County, Florida. It is concluded that the three

test operations described in this study contributed to the Corps of Engineers decision to advertise these projects on the basis of using material from the offshore zone for beach nourishment. It is also concluded that the shortage of sand and gravel and the feasibility of the hopper dredge pumpout operations will lead to a significant increase in the utilization of materials obtained from the offshore zone for general construction and beach nourishment purposes.

RECOMMENDATIONS

Recommendations for actions that should be taken in the near future are as follows:

A test operation to excavate material from the offshore zone and delivery of the material to an eroded beach should be scheduled by the Corps of Engineers. The test operation should include a mooring arrangement, utilizing a self-elevating DeLong Pier Barge equipped to handle the discharge pipeline connections. Utilization of such a barge would reduce the unit cost through the elimination of a floating mooring barge such as the MB-2. In addition, a DeLong Pier Barge elevated just above the water surface would act as a breakwater and permit the docking, unloading and undocking operations to continue under more severe wind and wave conditions than was possible during the three test operations discussed in this study.

As in the case of the Jacksonville test, there are instances when the total length of the discharge pipeline will exceed 8,000'. Therefore, the test operation should include the use of at least one booster pump unit.

The construction of an entrance channel for a Trident submarine base at Kings Bay, Georgia, must be completed prior to May, 1979. The conditions at this site are such that a test operation utilizing a self-elevating DeLong Pier Barge and two booster pump units would be feasible. Therefore, the Corps of Engineers should accomplish the Kings Bay, Georgia, work utilizing this procedure. In addition, a hopper dredge with sliding trunnion-dragarms should be utilized to minimize the fendering arrangements which are required when fixed trunnion-dragarms are used.

Future test operations should be scheduled when the propulsion and pumping machinery of hopper dredges are in good operating condition. Scheduling of the test operation at Virginia Beach, prior to an annual overhaul of the machinery, was necessary due to an emergency situation. Evaluation of the efficiency of an operation is difficult when the machinery of the hopper dredge is in poor condition.

The Corps of Engineers should procure three rubber-pneumatic fenders of the Yokohama type for use during future test operations.

The Corps of Engineers should procure two booster pump units for use during future test operations. Each of these units should have at least 2,000 horsepower to drive the booster pump and a discharge diameter of 24-inches or more.

Recommendations for future study are as follows:

An evaluation should be made of the feasibility of utilizing a flexible and buoyant type of rubber pipeline to provide a connection between a DeLong Pier Barge and a submerged discharge pipeline.

A study should be made of the feasibility of designing components that could readily be constructed into trestle section units so that the use of submerged discharge pipelines could be minimized.

A study should be made of the feasibility of utilizing a large buoy equipped with multiple anchors and a flexible and buoyant rubber discharge pipeline that could be coupled to the discharge pipeline connection of a hopper dredge. While a barge type mooring arrangement will be required in some cases, such as at the Jacksonville site and other locations with limited maneuvering space, a buoy type of arrangement could provide the most efficient operation in the offshore zone.

The Inner Continental Shelf Sediment and Structure Survey, formerly called the Sand Inventory Program, being

conducted by the Coastal Engineering Research Center of the Corps of Engineers should be scheduled for completion at an early date so that an assessment can be made of the quantities of material that are available and suitable for general construction and beach nourishment purposes.

A study should be made on a national basis to determine the eroded beaches which are within a reasonable distance of the offshore deposits of suitable materials. The study should include an evaluation of the volumes and types of material in the offshore deposits, including navigation channels; the volume of material needed at each eroded beach; the hopper dredge transit distances; and the total length ranges of the discharge pipelines required. This information would permit a reasonable operational, environmental and economic analysis of the extent that material from the offshore zone and navigation channels could be used to nourish eroded beaches.

The results available from future test operations should be consolidated with the results of the three tests discussed in this study and a mathematical model developed for predicting cycle times and production rates for future operations.

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APPENDIX A

TABLES

TABLE 1

SHORELINE CHARACTERISTICS

REGION	TOTAL SHORE-LINE (miles)	SHORELINE EXPOSED (miles)	SHELTERED (miles)	HISTORICAL SHORE CHANGES CRITICAL EROSION (miles)	NON-CRITICAL EROSION (miles)	NON-ERODING (miles)	SHORELINE WITH BEACH (miles)	WITHOUT BEACH (miles)
North Atlantic	8,620	4,730	3,890	1,090	6,370	1,160	2,320	6,300
South Atlantic—Gulf	14,620	2,470	12,150	980	1,840	11,800	3,600	11,020
Lower Mississippi	1,940	810	1,130	30	1,550	360	830	1,110
Texas Gulf	2,500	370	2,130	100	260	2,140	380	2,120
Great Lakes	2,680	2,020	660	220	1,040	2,420	2,110	1,570
California	1,810	1,320	490	80	1,470	260	680	1,130
North Pacific	2,840	650	2,190	70	190	2,580	2,050	790
Alaska	47,300	20,250	27,050	100	5,000	42,200	Unknown	Unknown
Hawaii	930	900	30	30	80	820	180	750
TOTAL FOR NATION	84,240	34,520	49,720	2,700	17,800	63,740	12,150*	24,790*

*Not including Alaska

TABLE 2

SHORELINE OWNERSHIP AND USE

Region	OWNERSHIP Federal Government (miles)	State & Local Government (miles)	Private (miles)	Uncertain (miles)	SHORE USE Recreation Public (miles)	Recreation Private (miles)	Non-Recreational Development (miles)	Undeveloped (miles)
North Atlantic	580	840	7,200	0	1,020	2,600	2,430	2,570
South Atlantic–Gulf	1,870	1,960	8,250	2,540	690	1,500	2,440	9,990
Lower Mississippi	240	330	1,370	0	20	30	50	1,840
Texas Gulf	390	50	2,060	0	400	160	110	1,830
Great Lakes	130	520	3,030	0	370	1,220	250	1,840
California	380	350	1,080	0	440	190	230	950
North Pacific	240	270	2,310	0	350	120	190	2,180
Alaska	41,350	5,500	450	0	10	0	330	46,960
Hawaii	110	260	560	0	90	0	200	640
TOTAL FOR NATION	45,290	10,080	26,310	2,560	3,390	5,820	6,230	68,800

TABLE 6

SUMMARY OF TIME AND PRODUCTION DATA
SEA GIRT TEST, 27 MARCH-20 MAY 1966

	EFFECTIVE TIME -- MINUTES								PRODUCTION DATA				NON-EFFECTIVE TIME -- MINUTES								
DATE	TO CUT	PUMPING	TURNING	TO MB #2	DOCKING	PUMPOUT	UNDOCKING	TOTAL TIME	LOADS	CU. YDS. DELIVERED	AVERAGE C. Y. PUMPING MINUTE	AVERAGE C. Y. CYCLE MINUTE	FUEL & SUPPLIES	TO/FROM ANCHOR	NATURAL ELEMENTS	MB #2	MINOR REPAIRS	BETWEEN WORKS	MISC	TOTAL TIME	TOTAL TIME IN PERIOD (MINUTES)
Mar 27																		480		480	480
28	51	199	42	116	38	504	15	965	3	11,899	63.3	13.2						420	55	475	1,440
29	39	96	21	63	21	274	24	538	2	6,635	86.6	13.7	480	407			15			902	1,440
30	48	164	27	91	41	615	17	1003	3	14,814	111.2	16.8				380			57	437	1,440
31	65	163	47	72	33	641	33	1054	4	20,794	98.2	17.2		21		275	13		77	386	1,440
Apr 1	12	54	5	45	8	21		145								1295				1295	1,440
2																610				610	610
5													480							480	480
6																			220	220	220
7	19	103	44	74	20	231	7	498	1	3,539	75.2	10.0						154	120	274	772
8	73	240	51	126	54	852	32	1428	4	18,168	76.0	12.7							12	12	1,440
9	80	322	57	145	53	728	35	1420	5	25,580	80.2	17.9					20			20	1,440
10	65	261	47	103	53	397	22	948	4	20,683	77.2	19.3				12		295		307	1,255
11																			85	85	85
18																			162	162	162
May 10	33	37	6	54	23	94	10	257	1	3,378	91.3	13.1	480						43	523	780
11	64	254	48	150	55	429	25	1025	4	18,333	92.5	19.4				330	85			415	1,440
12	40	152	14	35	20	371	21	653	3	14,810	81.8	20.2			330	457				787	1,440
13	57	280	23	129	65	449	28	1031	4	18,634	75.1	21.2			395	14				409	1,440
14	99	387	30	139	55	618	42	1370	6	31,208	80.6	20.9				33			37	70	1,440
15	89	421	40	162	57	553	33	1355	5	26,770	68.6	21.5				85				85	1,440
16	34	167	16	51	30	231	17	546	3	14,848	67.9	20.5			894					894	1,440
17															1010			250		1260	1,260
19		55	19					74						45	770			81		896	970
20		28	8	26	7	32	18	119						26	30	640		325		1021	1,140
TOTALS	868	3383	545	1581	633	7040	379	14429	52	250,093	81.0 Per Load	18.7 Per Load	1440	499	3429	4131	133	2005	868	12505	26,934

TABLE 7

SUMMARY OF COST DATA -- SEA GIRT TEST OPERATION

FEATURE	COST ESTIMATED	COST ACTUAL
Design	25,000	30,000
Submerged Pipeline -- Install, Repair and Remove	57,000	51,480
Flexible Connection Assembly	15,000	38,008
Discharge Pipeline on Shore, Install, Repair and Remove	65,000	68,822
Fender System Modifications -- MB-2	50,000	48,137
Equip MB-2 for Ocean Operation	22,000	18,900
MB-2 Operation, 2 Week Test	20,000	15,000
Tug Operation, 2 Week Test	16,000	15,325
GOETHALS Rental	140,000	117,200
MB-2 Operation - 2 months	130,000	94,841
Tug Operation - 2 months	60,000	62,075
Miscl. Supply and Services	55,000	70,250
Philadelphia District		
Overhead	35,000	38,132
Supervision, Inspection and Report	10,000	12,000
TOTAL	$700,000	$680,170

TABLE 8

SUMMARY OF TIME & PRODUCTION DATA
JACKSONVILLE TEST

EFFECTIVE TIME -- MINUTES

DATE	TO CUT	PUMPING	TURNING	TO MB-1	DOCKING	PUMPOUT	UNDOCKING	TOTAL TIME
25 Mar	121	120	-	40	13	129	3	426
26	95	224	15	62	18	750	10	1,174
27	36	134	-	104	30	642	5	951
28	83	245	-	77	28	620	7	1,060
29	42	240	10	123	30	963	22	1,430
30	85	300	15	133	42	771	9	1,355
31	53	226	-	141	24	832	7	1,283
1 Apr	88	120	9	68	10	266	4	565
2	77	157	11	40	19	701	9	1,014
3	42	155	10	41	21	643	5	917
4	87	255	-	148	36	874	17	1,417
5	30	154	14	54	28	462	22	764
6	145	123	-	56	9	113	5	451
7	81	173	-	62	20	384	7	727
8	40	164	10	62	21	413	5	715
9	55	287	27	106	45	910	10	1,440
10	80	264	26	108	49	900	13	1,440
11	68	261	-	141	32	758	8	1,268
12	87	223	-	63	23	773	3	1,172
13	64	164	17	86	34	755	9	1,129
14	61	180	-	97	21	670	8	1,037
15	73	284	7	119	33	898	26	1,440
16	68	227	10	99	30	992	14	1,440
17	68	120	10	38	16	636	8	896
18	94	247	3	80	19	680	11	1,134
19	107	182	13	81	29	727	6	1,145
20	87	240	-	109	31	840	7	1,314
21	89	236	-	113	38	909	12	1,397
22	56	269	15	99	31	861	13	1,344
23	24	175	14	96	18	919	4	1,250
24	49	129	-	65	23	460	4	730
25	39	180	14	59	17	955	12	1,276
26	123	219	-	74	18	702	9	1,145
27	54	201	16	106	23	932	9	1,341
28	45	168	12	55	13	1,095	12	1,400
29	48	180	17	108	22	1,057	8	1,440
30	82	240	11	87	22	958	11	1,411
1 May	15	60	11	16	5	272	60	439
TOTALS	2641	7526	317	3216	941	27,222	414	42,277
AVERAGE	70	198	8	85	25	716	11	1,113

PRODUCTION DATA

DATE	# LOADS	CU YDS DELIVERED	AVG CY PER LOAD	AVG CYCLE TIME
25 Mar	1	4,135	4135	236
26	3	13,050	4350	398
27	3	8,943	2981	269
28	4	16,122	4031	297
29	5	20,473	4095	323
30	4	16,414	4104	312
31	4	13,069	3267	288
1 Apr	2	6,602	3301	329
2	2	5,838	2919	447
3	2	8,258	4129	443
4	4	14,764	3691	391
5	3	10,429	3476	316
6	2	5,838	2919	197
7	3	9,110	3037	246
8	2	5,507	2754	300
9	4	12,998	3250	319
10	5	17,693	3537	341
11	5	10,971	2194	260
12	3	8,578	2859	363
13	3	7,986	2662	355
14	3	5,801	1934	285
15	5	11,782	2356	305
16	4	11,737	2934	366
17	3	7,370	2457	366
18	3	10,812	3604	343
19	3	8,613	2871	392
20	4	10,909	2727	306
21	5	15,100	3020	313
22	4	12,949	3237	326
23	3	10,647	3549	431
24	2	4,349	2175	232
25	4	15,973	3933	389
26	3	9,869	3290	361
27	3	8,361	2787	399
28	3	10,021	3340	509
29	3	10,754	3585	410
30	5	15,273	3055	340
1 May	1	3,072	3072	439
TOTALS	125	400,170	-	-
AVERAGE			3201	338

NON-EFFECTIVE TIME -- MINUTES

DATE	FUEL & SUPPLY	TO/FROM ANCHOR	NATURAL ELEMENTS	MB-1	MINOR REPAIRS	BETW WORKS	MISC	TOTAL TIME	TIME IN PERIOD
25 Mar	480	-	-	39	-	-	-	519	945
26	-	-	117	-	-	-	-	117	1,440
27	-	-	460	-	-	-	-	460	1,440
28	-	-	358	-	-	-	-	358	1,440
29	-	-	-	-	-	-	10	10	1,440
30	-	-	70	-	-	-	10	80	1,440
31	-	-	-	25	124	-	-	149	1,440
1 Apr	-	-	-	195	14	-	480	689	1,440
2	-	-	28	261	-	-	-	289	1,440
3	480	41	-	-	-	-	-	521	1,440
4	-	-	-	23	-	-	-	23	1,440
5	-	-	-	20	107	-	340	467	1,440
6	-	-	-	145	-	-	255	400	1,440
7	-	-	-	36	-	-	160	196	1,440
8	480	188	-	-	-	-	43	711	1,440
9	-	-	-	-	-	-	-	0	1,440
10	-	-	-	-	-	-	-	0	1,440
11	-	-	-	-	162	-	-	162	1,440
12	-	-	-	-	252	-	-	252	1,440
13	-	-	-	-	-	-	33	33	1,440
14	-	-	-	-	355	-	24	379	1,440
15	-	-	-	-	-	-	-	0	1,440
16	-	-	-	-	-	-	-	0	1,440
17	480	33	27	-	-	-	-	540	1,440
18	-	-	-	-	104	-	40	144	1,440
19	-	-	-	-	268	-	10	278	1,440
20	-	-	-	-	-	-	119	119	1,440
21	-	-	-	-	-	-	40	40	1,440
22	-	-	-	-	-	-	90	90	1,440
23	-	-	-	30	-	-	10	40	1,440
24	480	28	-	-	-	-	188	696	1,440
25	-	-	-	-	-	-	55	55	1,440
26	-	-	-	-	-	-	38	38	1,440
27	-	-	-	-	82	-	12	94	1,440
28	-	-	-	-	38	-	-	38	1,440
29	-	-	-	-	-	-	-	0	1,440
30	-	-	-	-	27	-	-	27	1,440
1 May	420	32	-	-	43	-	20	515	960
TOTALS	2820	322	1060	774	1576	-	1977	8529	53,745

TABLE 9

SUMMARY OF COST DATA -- JACKSONVILLE TEST OPERATION

FEATURE	COST ESTIMATED	COST ACTUAL
Design	$ 6,500	$ 7,450
Mobilization		
GOETHALS	43,500	44,700
MB-1	29,000	31,080
Preparation of MB-1		
Tugs, Crane & Rigging Crew	8,500	9,500
Disposal Operations		
MB-1 Rental and Crew	110,000	114,400
Rental of Pipeline	36,000	38,660
Equipment Rental & Supplies	16,000	18,440
Beach Shaping Operations	9,500	10,750
Consultant Fees	2,400	2,185
GOETHALS Rental	538,000	541,315
Demobilization		
Preparation and Tow of MB-1	45,000	48,610
Pipeline	16,000	18,320
Jacksonville District		
Surveys	14,000	12,400
Supervision & Inspection	15,000	16,900
Overhead	5,100	4,450
TOTAL	$894,500	$919,160

TABLE 10

SUMMARY OF TIME AND PRODUCTION DATA -- VIRGINIA BEACH TEST
6 OCTOBER-25 NOVEMBER 1974
(Page 1 of 2)

	EFFECTIVE TIME -- MINUTES								PRODUCTION DATA					NON-EFFECTIVE TIME -- MINUTES								
DATE	TO CUT	PUMPING	TURNING	TO MB #2	DOCKING	PUMPOUT	UNDOCKING	TOTAL TIME	LOADS	CU. YDS. DELIVERED	AVERAGE CU. YDS. PER LOAD	AVG. CYCLE TIME PER LOAD	PUMPOUT/ PUMPING RATIO	FUEL AND SUPPLIES	TO/FROM ANCHOR	NATURAL ELEMENTS	MB #2	MINOR REPAIRS	BETWEEN WORKS	MISC.	TOTAL TIME	TOTAL TIME IN PERIOD (MINUTES)
Oct 6	109	182	9	83	19	175	3	580	1	3,374	3374	366	1.4							39	39	619
7	145	423	15	142	94	506	18	1339	5	19,241	3848	302	1.0				101				101	1440
8	77	70	-	35	15	95	3	295	1	2,887	2887	263	1.6								-	295
9	95	207	22	68	22	249	4	667	1	3,487	3487	324	1.2	480	188		105				773	1440
10	89	480	45	129	52	482	8	1285	4	15,367	3842	361	1.1					145		10	155	1440
11	78	556	-	143	36	424	11	1248	5	17,339	3468	275	0.8					29			29	1277
12	46	281	15	87	31	315	8	783	3	11,997	3999	293	0.9					282			282	1065
13	172	458	-	87	25	315	6	1063	3	10,413	3471	303	0.9								-	1063
14	95	399	19	122	44	557	15	1251	5	14,288	2858	276	1.1			189					189	1440
15	82	621	8	144	47	460	13	1375	5	17,423	3485	253	0.9					10		55	65	1440
16	165	180	47	57	14	265	4	732	1	4,498	4498	381	1.1	480	228						708	1440
17	72	605	36	131	29	511	16	1404	5	22,340	4468	377	0.9							36	36	1440
18	133	652	57	126	33	412	11	1424	4	16,780	4195	324	0.7				16				16	1440
19	97	548	115	110	33	513	13	1429	4	16,762	4191	364	0.9							11	11	1440
20	66	551	60	157	30	540	26	1430	4	17,383	4346	383	0.9				10				10	1440
21	102	541	56	122	23	536	6	1386	3	14,376	4792	433	1.1					35		19	54	1440
22	96	527	77	116	29	554	10	1410	3	14,109	4703	404	1.0							30	30	1440
23	158	175	8	64	8	121	4	538	2	5,762	2881	264	1.3	480	218			204			902	1440
24	86	345	10	101	39	526	6	1113	3	9,489	3163	364	1.0					327			327	1440
25	63	545	55	128	37	600	12	1440	4	16,951	4238	359	1.1								-	1440
26	75	540	19	170	36	561	19	1420	5	20,207	4041	347	1.0				20				20	1440
27	101	622	-	124	21	419	10	1297	4	17,209	4302	305	0.8				40	103			143	1440
28	86	630	41	146	32	473	12	1420	4	16,111	4028	313	0.8				20				20	1440
29	77	570	45	114	21	524	11	1362	4	17,533	4383	341	1.0				7			71	78	1440
30	167	162	-	23	7	301	6	666	2	9,686	4843	444	1.0	480	294						774	1440
31	85	540	14	95	19	492	9	1254	3	14,193	4731	371	1.2				37	135		14	186	1440
TOTALS	2617	11,410	773	2824	796	10,926	264	29,611	88	349,206	-	-	-	1920	928	189	356	1270	-	285	4948	34,559
AVERAGE	30	130	9	32	9	124	3	336			3968	336	1.0									

TABLE 10

SUMMARY OF TIME AND PRODUCTION DATA -- VIRGINIA BEACH TEST
6 OCTOBER-25 NOVEMBER 1974
(Page 2 of 2)

EFFECTIVE TIME -- MINUTES; PRODUCTION DATA; NON-EFFECTIVE TIME--MINUTES

DATE	TO CUT	PUMPING	TURNING	TO MB #2	DOCKING	PUMPOUT	UNDOCKING	TOTAL TIME	LOADS	CU. YDS. DELIVERED	AVERAGE CU. YDS. PER LOAD	AVG. CYCLE TIME PER LOAD	PUMPOUT/ PUMPING RATIO	FUEL AND SUPPLIES	TO/FROM ANCHOR	NATURAL ELEMENTS	MB #2	MINOR REPAIRS	BETWEEN WORKS	MISC.	TOTAL TIME	TOTAL TIME IN PERIOD (MINUTES)
Nov 1	87	464	19	96	34	704	12	1416	4	17,627	4407	383	1.3				24				24	1440
2	84	526	45	135	28	560	13	1391	4	19,435	4859	356	1.0				29			20	49	1440
3	86	578	26	142	45	551	12	1440	4	17,392	4348	355	1.0								-	1440
4	81	587	9	130	30	531	13	1381	4	16,957	4239	344	0.9				59				59	1440
5	48	608	76	102	22	508	13	1373	3	10,215	3405	416	1.1				25			42	67	1440
6	145	146	24	56	15	190	3	579	1	4,273	4273	348	0.9	480	310			71			861	1440
7	113	518	-	130	27	509	10	1307	4	14,176	3544	368	1.0				12	121			133	1440
8	77	319	26	61	12	366	12	873	3	11,634	3878	343	1.0			525	42				567	1440
9	67	460	62	137	25	372	8	1130	3	12,465	4155	372	0.9				30	255		25	310	1440
10	92	596	8	162	33	537	12	1440	4	17,452	4338	326	1.0								-	1440
11	81	537	31	120	24	529	11	1330	4	15,901	3975	294	0.9				55	52			107	1440
12	99	581	-	144	28	498	15	1365	5	16,895	3379	321	0.9							75	75	1440
13	143	206	-	77	17	249	3	695	1	3,616	3616	296	1.0	480	235			30			745	1440
14	104	575	28	138	33	532	12	1422	4	17,584	4396	395	1.1				18				18	1440
15	104	507	18	140	21	638	12	1440	4	17,365	4341	396	1.3								-	1440
16	93	503	-	158	28	517	11	1310	4	17,757	4438	346	0.9					130			130	1440
17	66	518	23	161	31	545	12	1358	4	17,765	4441	358	1.0				82				82	1440
18	92	540	42	149	27	487	10	1347	3	13,647	4549	370	1.0				19	74			93	1440
19	74	440	37	217	42	453	9	1272	4	16,177	4044	313	1.1			149	19				168	1440
20	158	140	-	37	7	223	5	570	2	8,348	4174	415	1.0	480	263	127					870	1440
21	56	560	70	142	39	461	8	1336	3	13,290	4430	360	0.9					74		30	104	1440
22	107	526	46	121	29	597	14	1440	5	20,165	4033	331	1.0								-	1440
23	89	575	39	104	30	508	10	1355	4	17,854	4464	339	0.9					85			85	1440
24	82	528	33	127	31	519	10	1330	4	18,892	4723	341	0.9					110			110	1440
25	6	140	-	41	10	124	3	324	1	4,435	4435	341	0.9								-	324
TOTALS	2236	11,678	662	3027	668	11,703	253	30,227	86	361,312	-	-	-	1440	808	801	414	1002	-	192	4657	34,844
AVERAGE	26	136	8	35	8	136	3	352			4201	352	1.0									

TWO MONTH TOTALS

	TO CUT	PUMPING	TURNING	TO MB #2	DOCKING	PUMPOUT	UNDOCKING	TOTAL TIME	LOADS	CU. YDS. DELIVERED	AVERAGE CU. YDS. PER LOAD	AVG. CYCLE TIME PER LOAD	PUMPOUT/ PUMPING RATIO	FUEL AND SUPPLIES	TO/FROM ANCHOR	NATURAL ELEMENTS	MB #2	MINOR REPAIRS	BETWEEN WORKS	MISC.	TOTAL TIME	TOTAL TIME IN PERIOD (MINUTES)
TOTALS	4853	23,088	1435	5851	1464	22,629	517	59,838	174	710,518	-	-	-	3360	1736	990	770	2272	-	477	9605	69,403
AVERAGE	28	133	8	34	8	130	3	344			4083	344	1.0									

TABLE 11

SUMMARY OF COST DATA -- VIRGINIA BEACH
TEST OPERATION

FEATURE	COST ESTIMATED	COST ACTUAL
Design	$ 17,000	$ 22,152
Modifications to MB-1	20,000	22,530
Towing -- MB-1	2,500	2,000
Modifications to MB-2	80,000	134,776
Towing -- MB-2	5,000	5,350
Flexible Connection Assembly	10,000	14,000
Philadelphia District Overhead Rates on Their Equipment	44,500	51,480
Consultant Fees	8,000	9,245
MB-2 Rental	68,000	74,391
Foam Fenders	15,000	17,820
Geophysical Sub-bottom Survey	3,000	3,525
Fort Eustis -- Labor & Materials	15,000	17,150
Submerged Pipeline -- Install, Repair and Remove	17,000	15,930
GOETHALS Rental	780,000	801,890
Norfolk District		
Operational Costs	100,000	107,870
Supervision & Inspection	30,000	37,060
Overhead	15,000	16,647
TOTAL	$1,230,000	$1,353,816

APPENDIX B

FIGURES

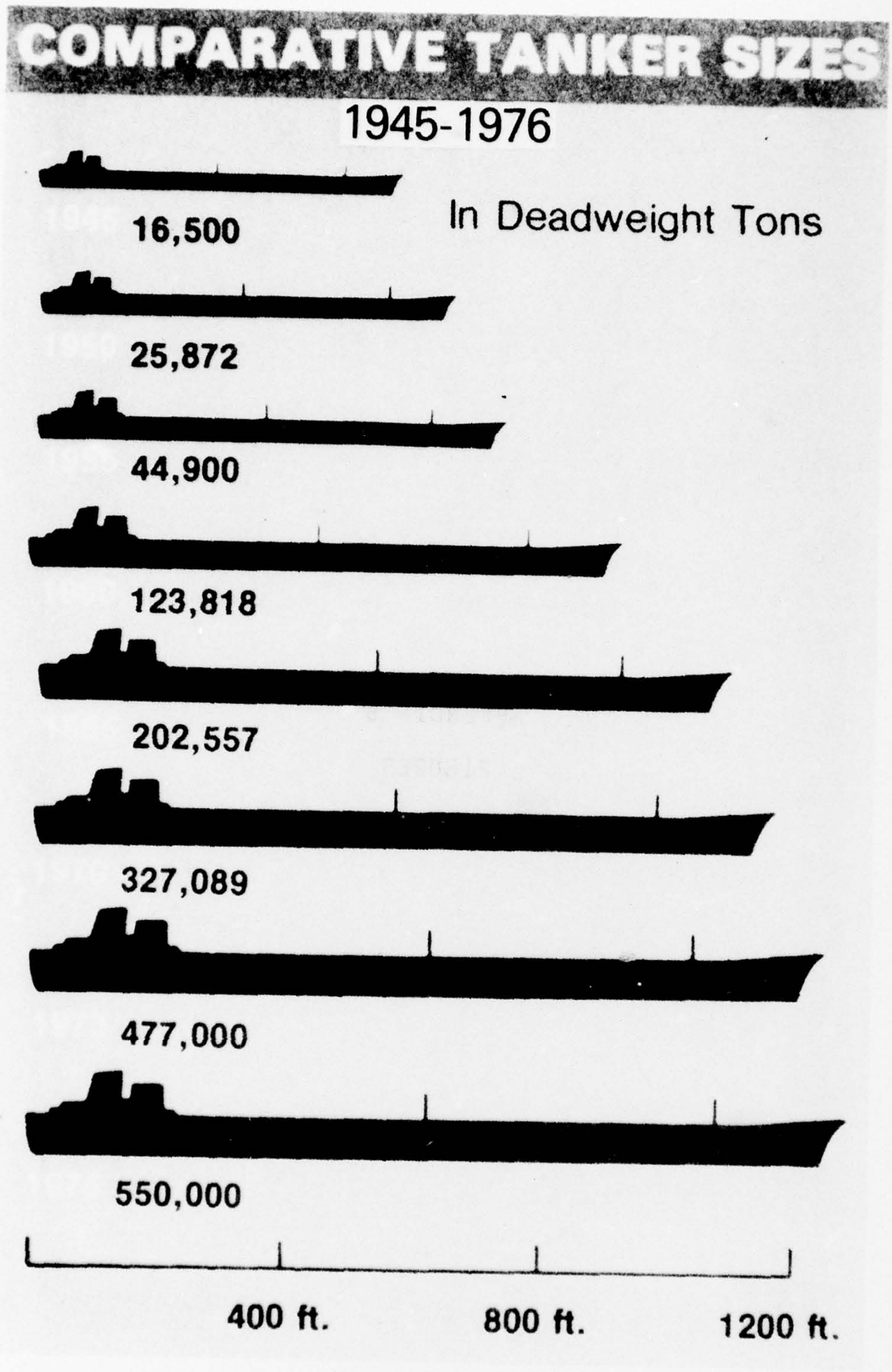

COMPARATIVE TANKER SIZES
1945-1976
In Deadweight Tons
16,500
25,872
44,900
123,818
202,557
327,089
477,000
550,000
400 ft.
800 ft.
1200 ft.

FIGURE 1

FIGURE 2

DESIGN FEATURES -- HOPPER DREDGE GOETHALS
U. S. ARMY, CORPS OF ENGINEERS

FEATURE	DESCRIPTION
Length, Overall	476 feet, 5 inches
Beam, Molded	68 feet, 0 inches
Draft -- Controlling	
Light	22 feet, 0 inches
Loaded	29 feet, 6 inches
Maximum Dredging Depth	65 feet, 0 inches
Hopper Capacity	6,422 cubic yards
Propulsion -- Twin Steam Turbines	
Power -- Total	6,000 horsepower
Dredging System -- Twin Pumps	
Power -- Total	6,000 horsepower
Suction Diameter/Pump	32 inches
Discharge Diameter/Pump	30 inches
Speed	
Light	14.5 MPH
Loaded	13.5 MPH
Length to Beam Ratio	6.7
Watertight Compartments	15
Certification	Oceans

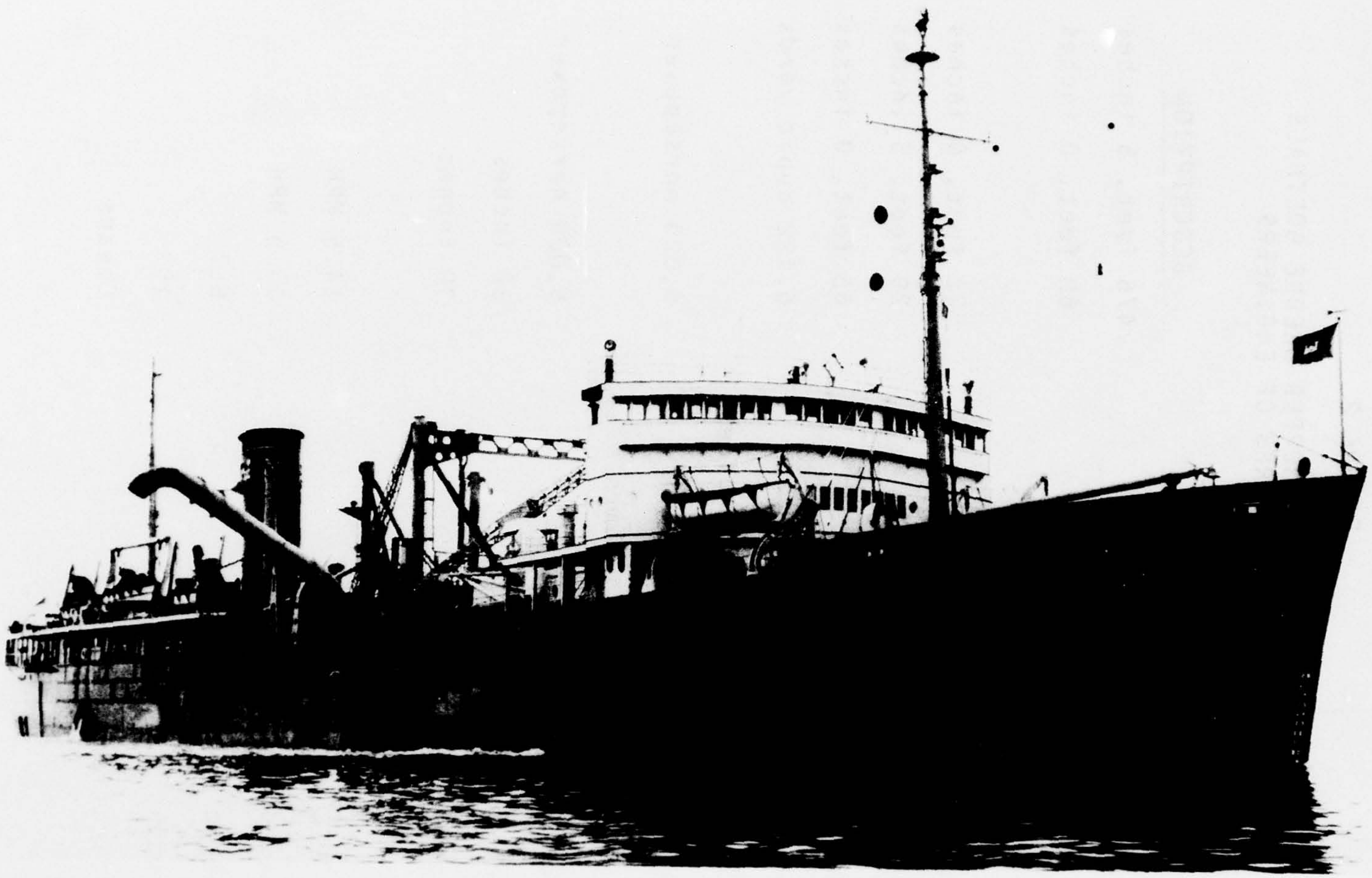
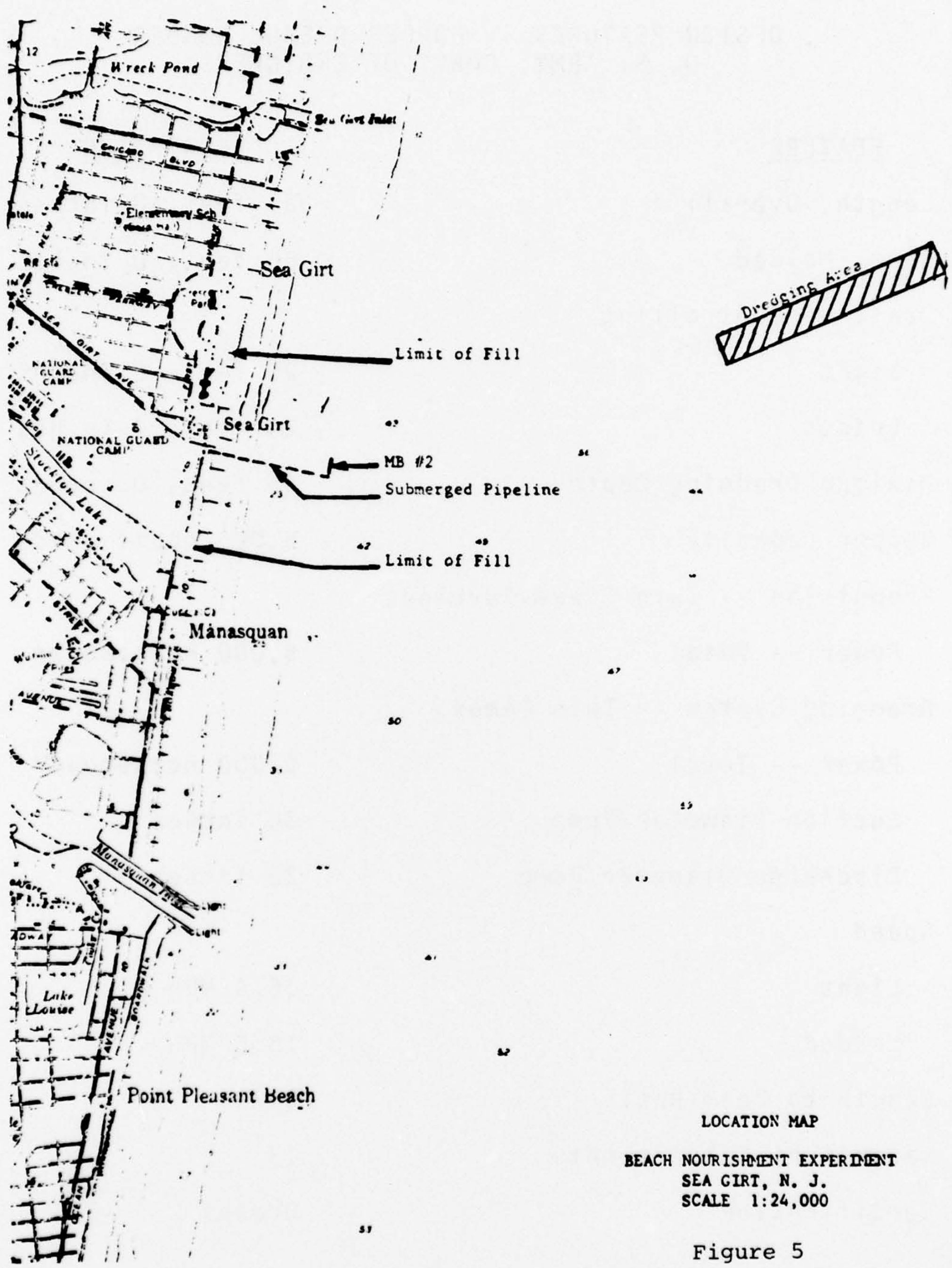


Figure 3. Hopper Dredge Goethals U.S. Army, Corps of Engineers Philadelphia District.

FIGURE 4

DESIGN FEATURES -- HOPPER DREDGE COMBER
U. S. ARMY, CORPS OF ENGINEERS

FEATURE	DESCRIPTION
Length, Overall	351 feet, 8 inches
Beam, Molded	60 feet, 0 inches
Draft -- Controlling	
Light	20 feet, 0 inches
Loaded	24 feet, 4 inches
Maximum Dredging Depth	65 feet, 0 inches
Hopper Capacity	6,000 cubic yards
Propulsion -- Twin Steam Turbines	
Power -- Total	6,000 horsepower
Dredging System -- Twin Pumps	
Power -- Total	6,000 horsepower
Suction Diameter/Pump	30 inches
Discharge Diameter/Pump	28 inches
Speed	
Light	15.4 MPH
Loaded	13.5 MPH
Length to Beam Ratio	5.7
Watertight Compartments	13
Certification	Oceans



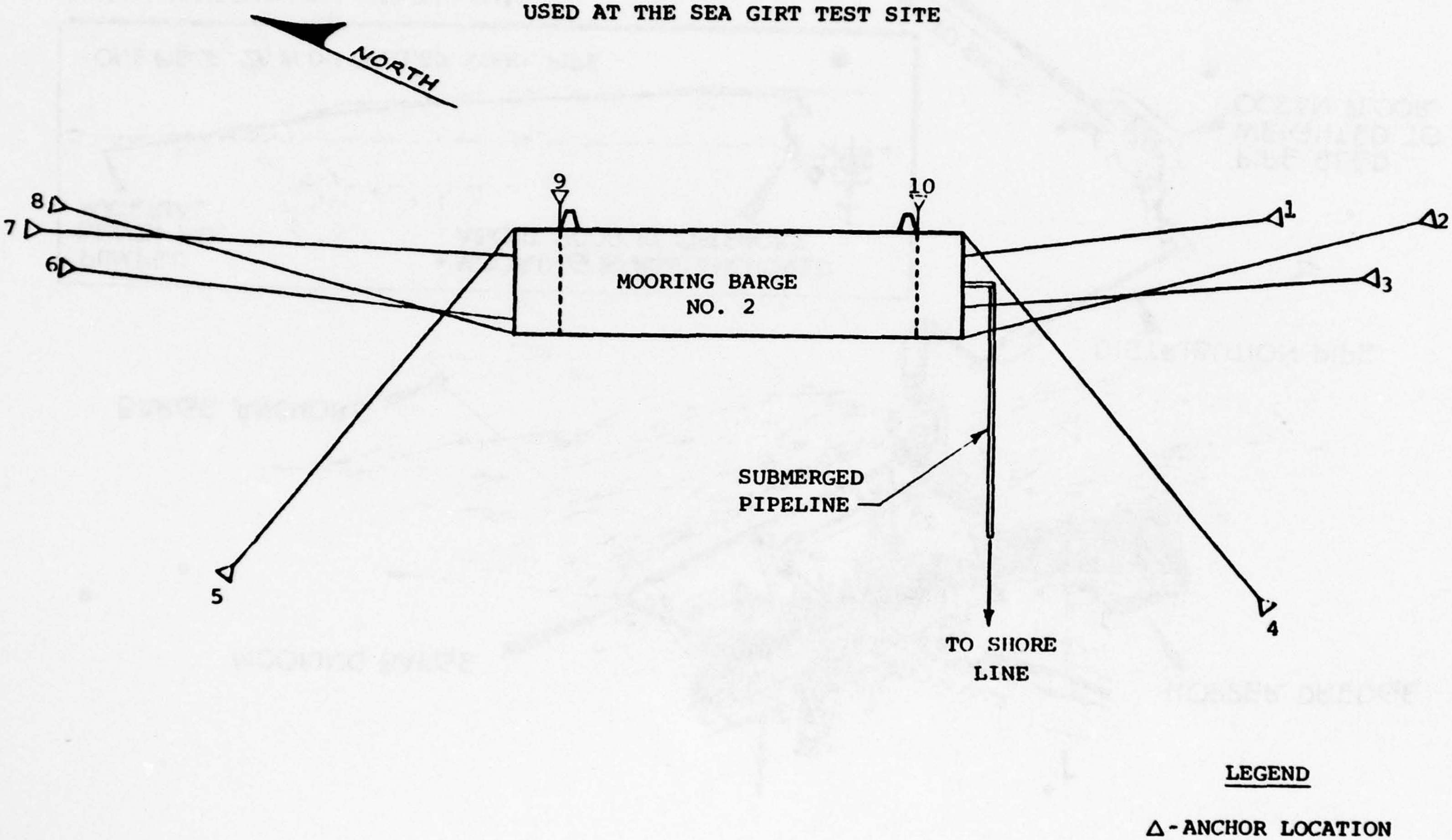
LOCATION MAP

BEACH NOURISHMENT EXPERIMENT
SEA GIRT, N. J.
SCALE 1:24,000

Figure 5

FIGURE 6

SKETCH OF BUOY AND ANCHORING SYSTEM
USED AT THE SEA GIRT TEST SITE



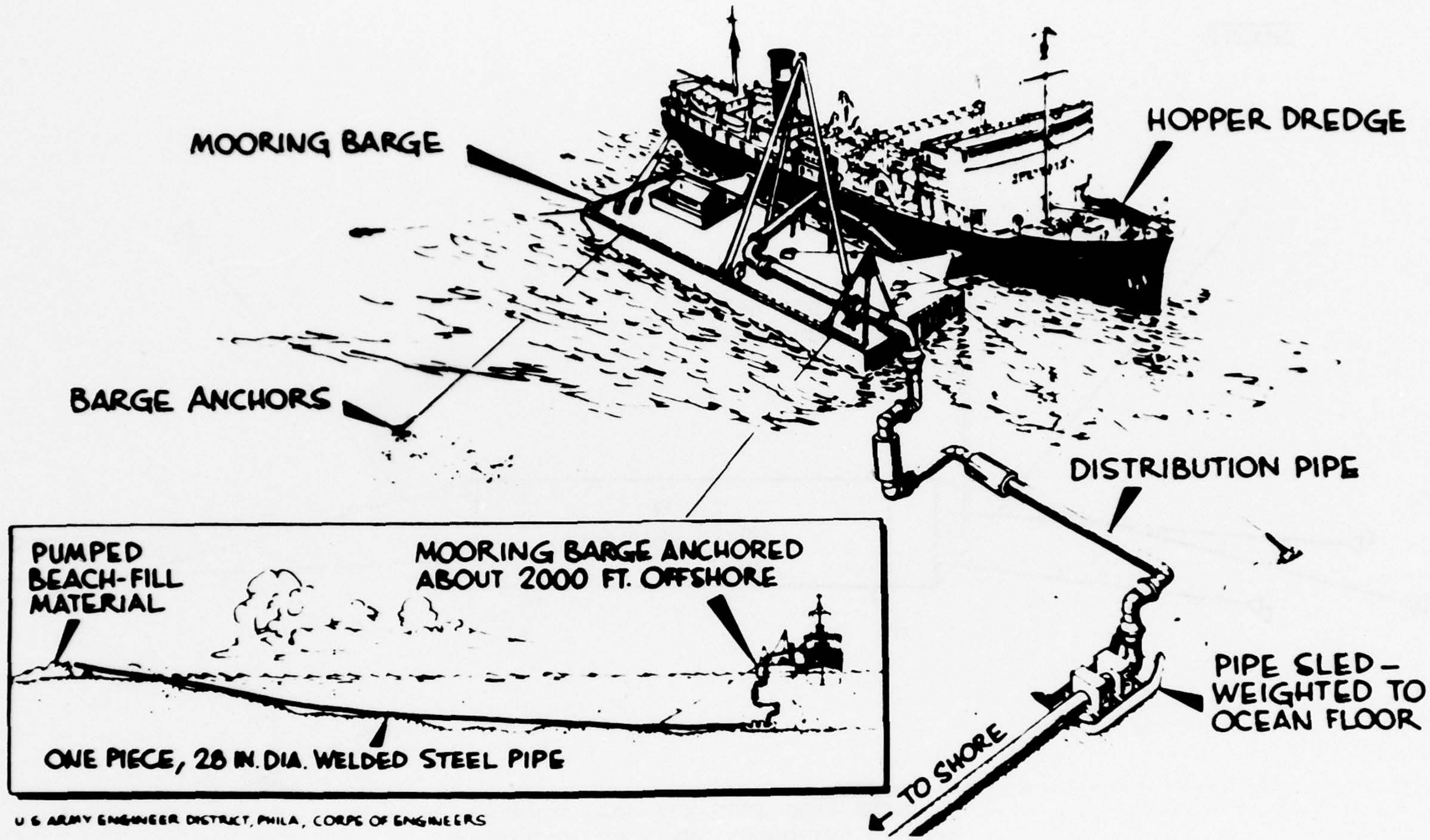


Figure 7. Artist Sketch Showing the Mooring Arrangement and the Distribution Pipeline Layout Used at the Sea Girt Test Site.

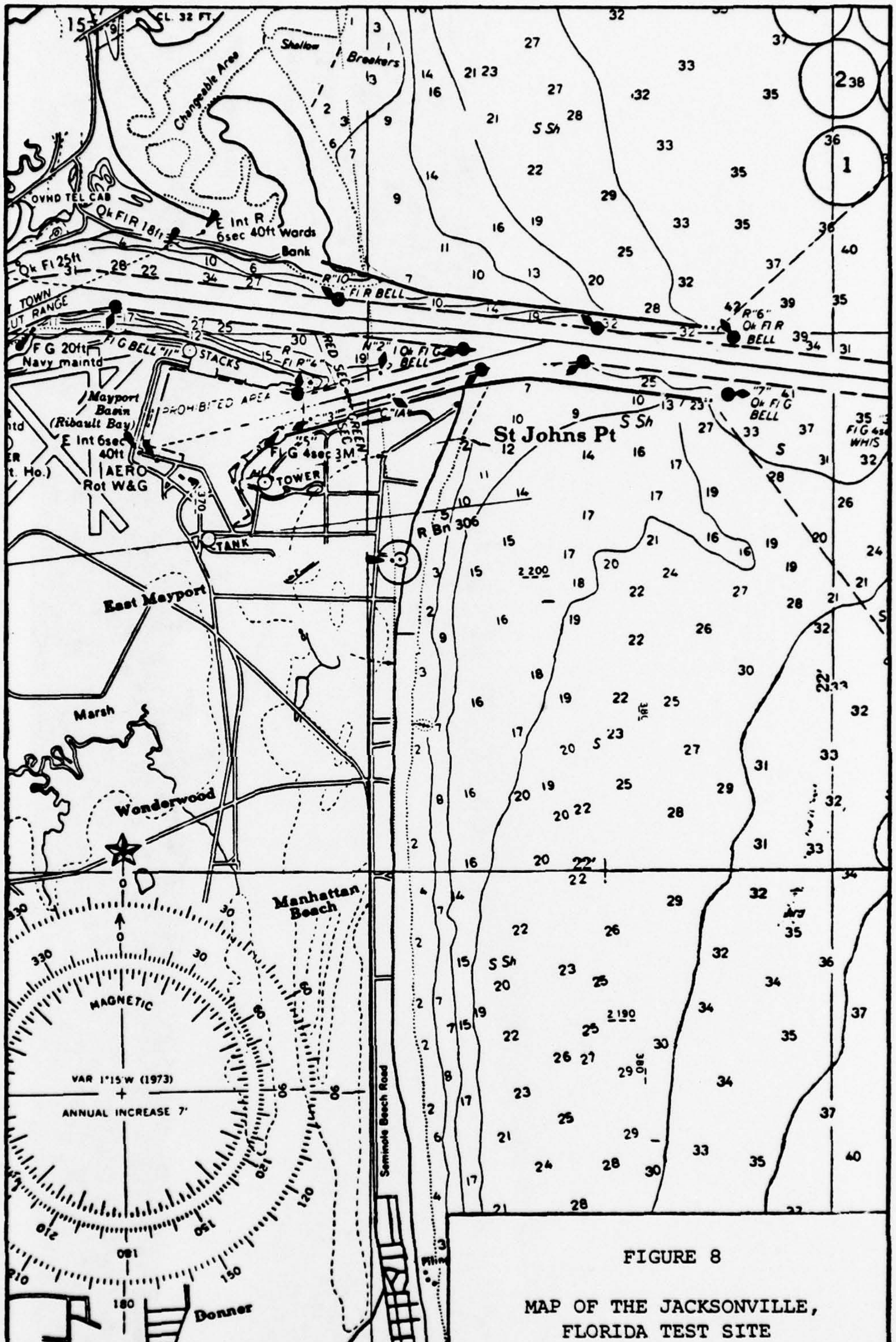


FIGURE 8

MAP OF THE JACKSONVILLE, FLORIDA TEST SITE

Figure 9. Hopper Dredge Goethals Moored to the MB-1 at the Jacksonville, Florida Test Site.

FIGURE 10

DESIGN FEATURES -- MOORING BARGE NO. 1
U. S. ARMY, CORPS OF ENGINEERS

FEATURE	DESCRIPTION
Length, Overall	250 feet, 6 inches
Beam, Molded	60 feet, 0 inches
Draft -- Controlling	
Light	3 feet, 4 inches
Loaded	4 feet, 0 inches
A Frame	
Height	82 feet, 0 inches
Capacity	52 short tons
Spuds	
Number	4
Diameter/Each	6 feet, 0 inches
Length/Each	60 feet, 0 inches
Weight/Each	16 tons
Number of Winches	
Mooring Lines	2
Spud Lines	4
Discharge Pipeline	1

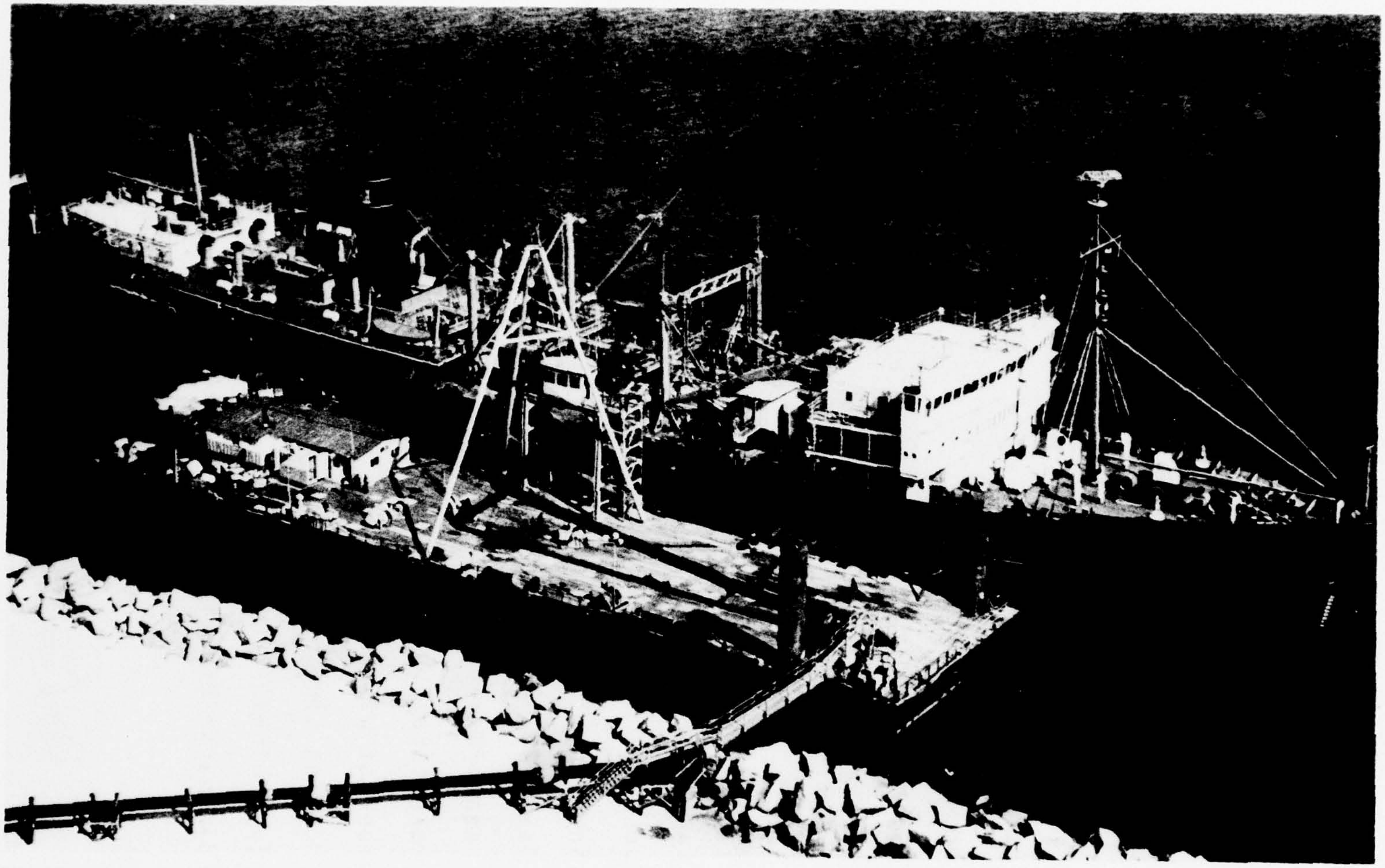


Figure 11. Hopper Dredge Goethals and MB-1 Berthing Arrangement--Jacksonville, Florida Test Site.

Figure 12. Aerial View of Jacksonville, Florida Shoreline Near the End of the Test Operation.

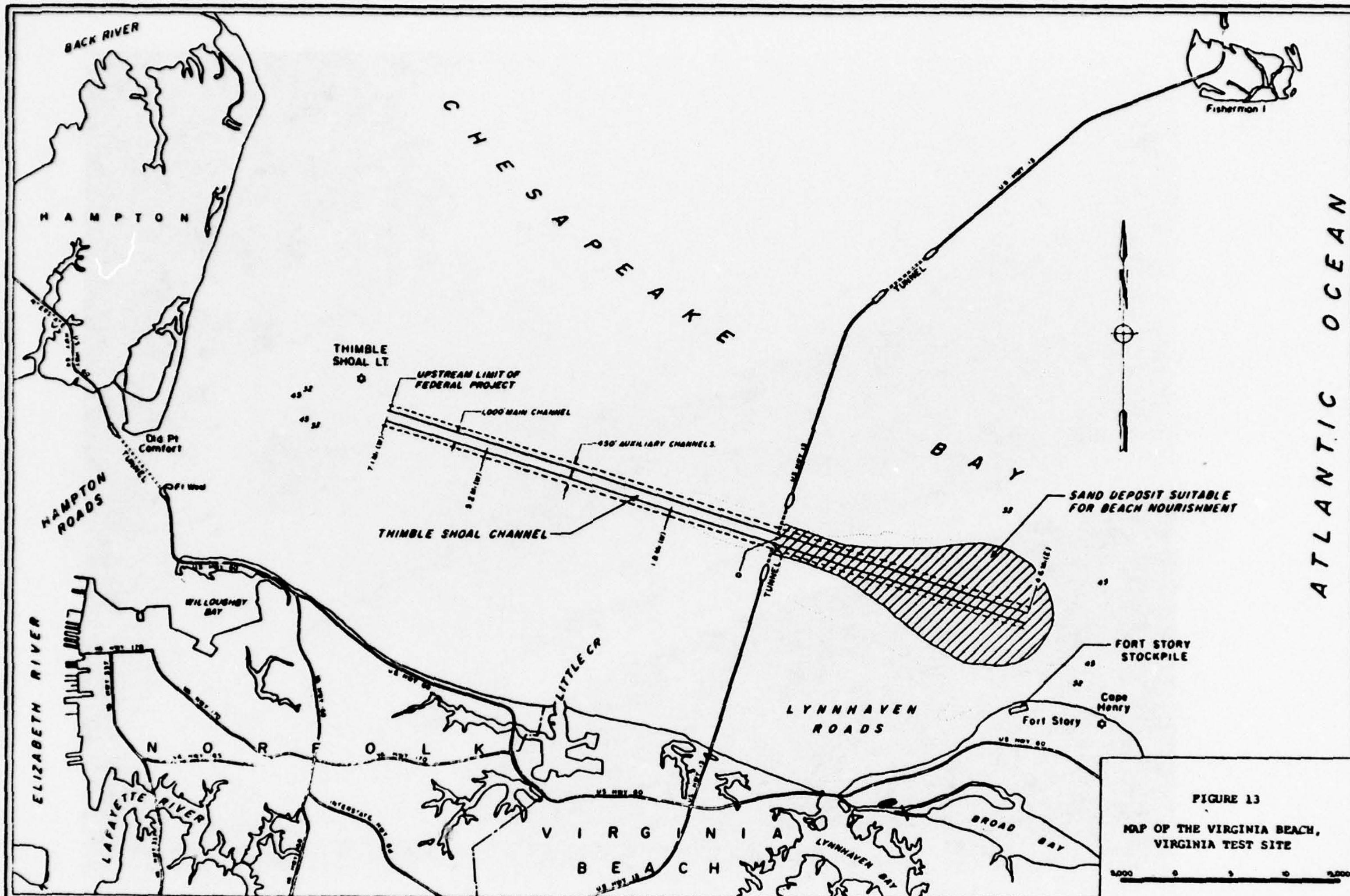


FIGURE 13

MAP OF THE VIRGINIA BEACH, VIRGINIA TEST SITE

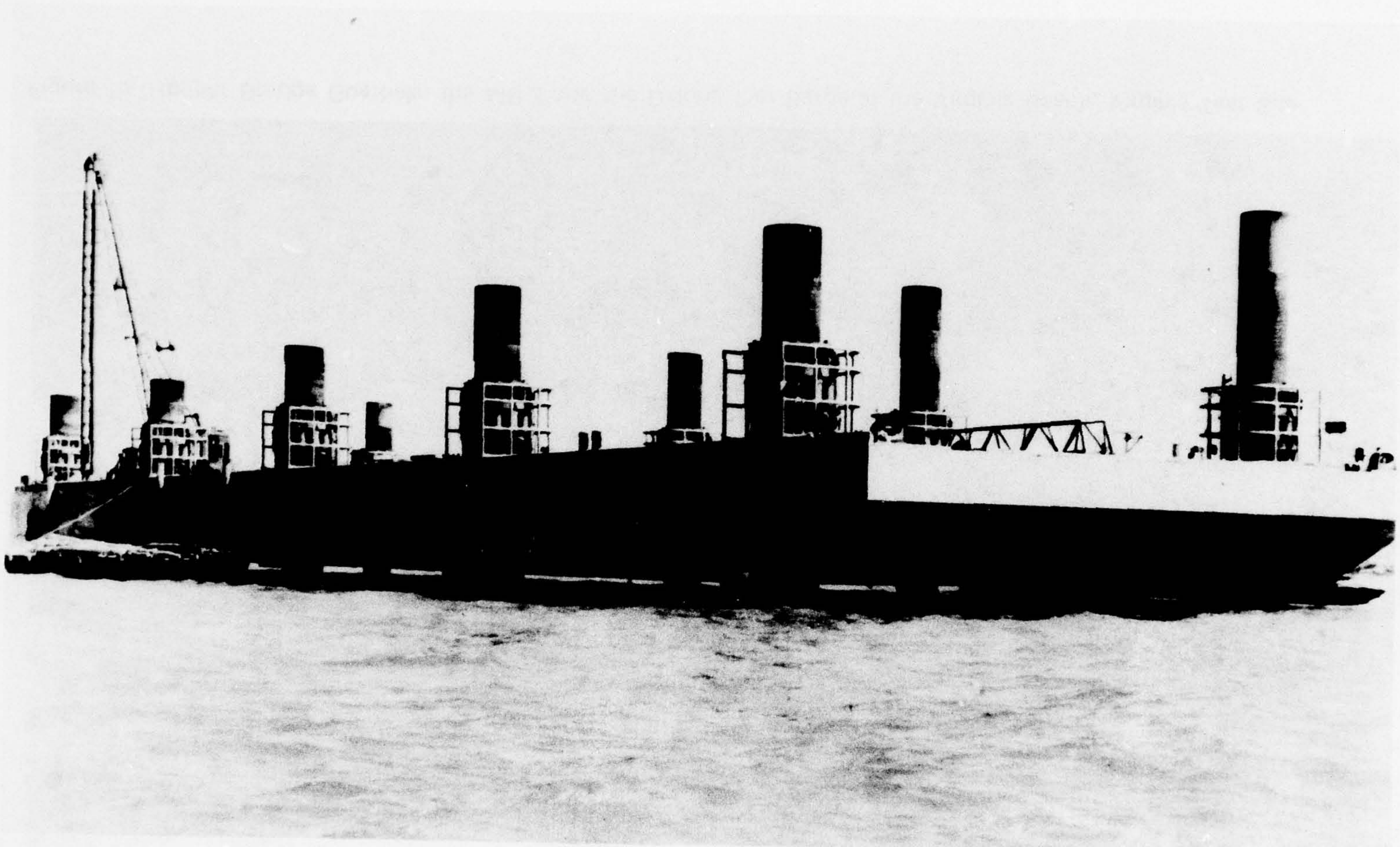


Figure 14. Delcng Pier Barge at the Virginia Beach, Virginia Test Site.

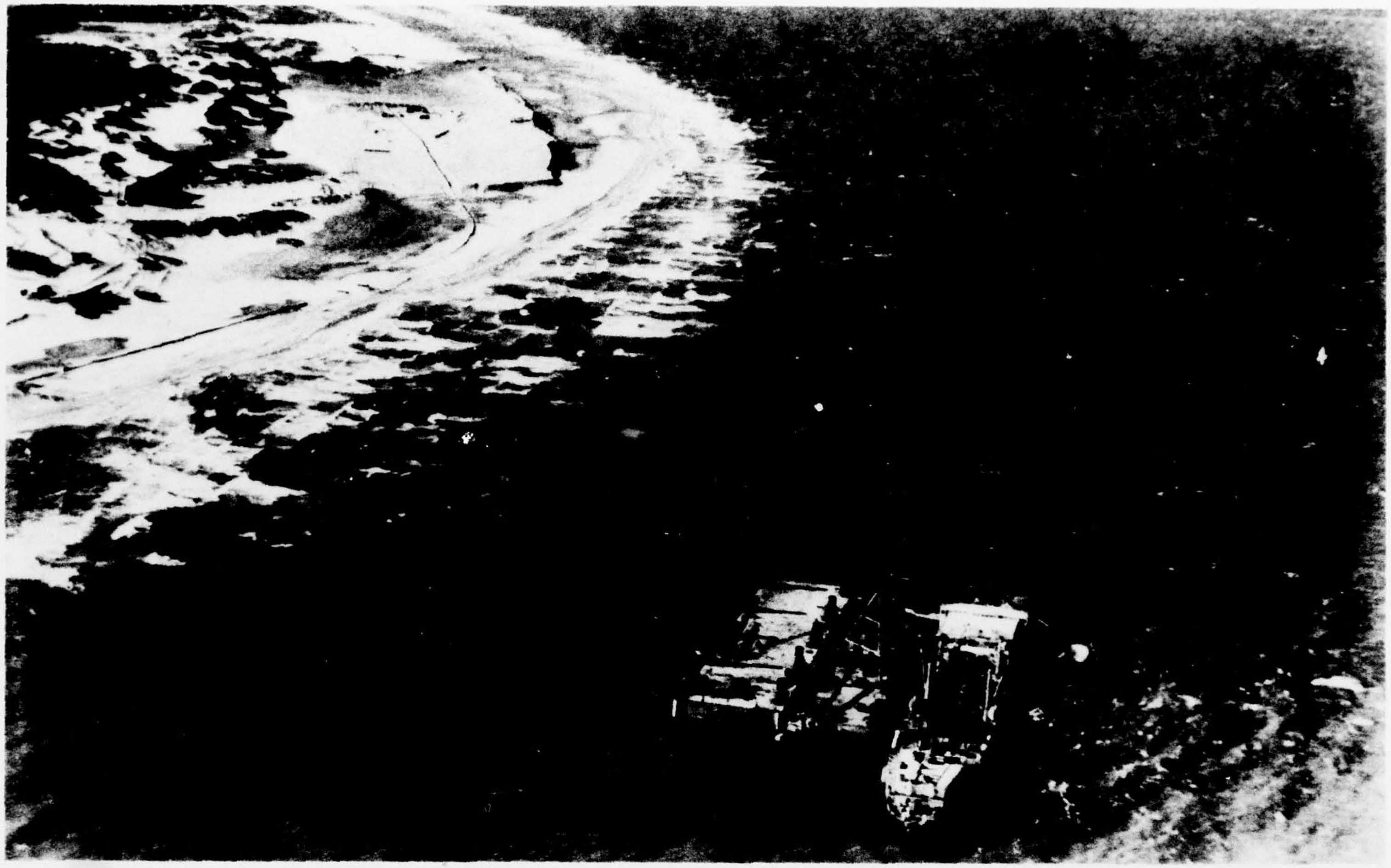


Figure 15. Hopper Dredge Goethals, the MB-2 and the Delong Pier Barge at the Virginia Beach, Virginia Test Site.

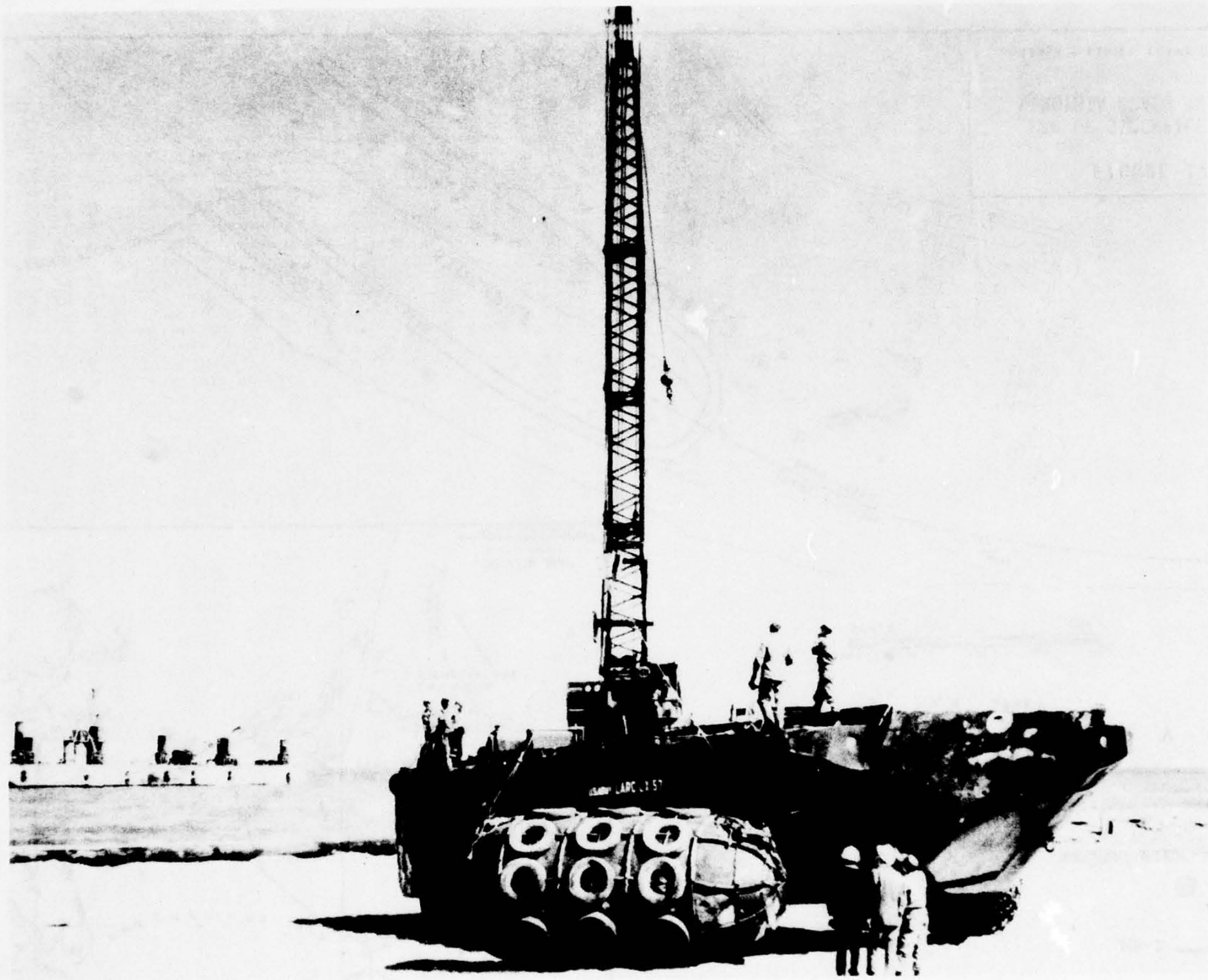


Figure 16. Yokohama Rubber-Pneumatic Type of Fender.

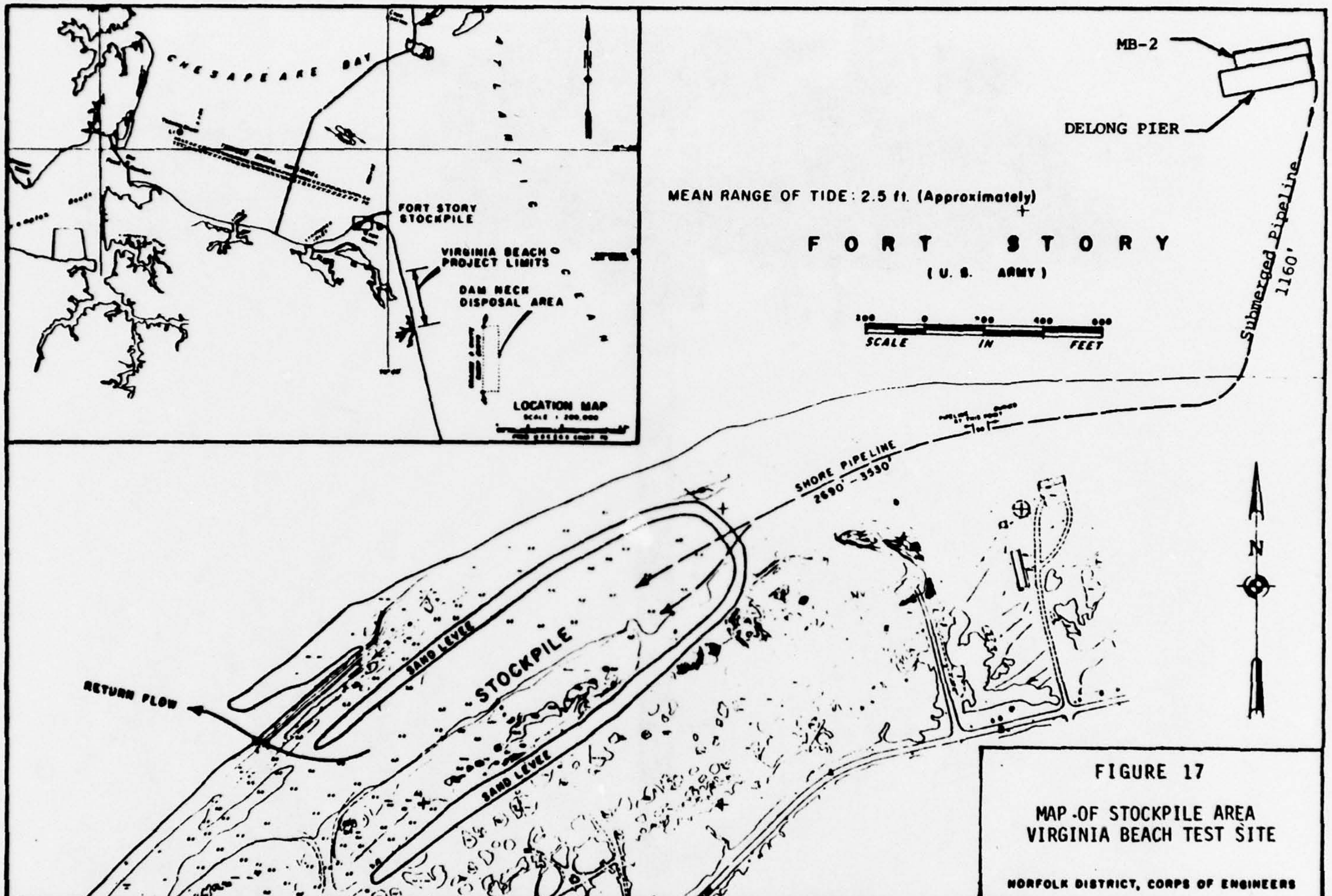


FIGURE 17

MAP OF STOCKPILE AREA
VIRGINIA BEACH TEST SITE

NORFOLK DISTRICT, CORPS OF ENGINEERS